ABSTRACT

Title of Thesis: INVISIBLE CRISIS

Gregory Goldstein, Master of Architecture, 2018

Thesis Directed By: Professor, Karl DuPuy, University of Maryland School of Architecture Planning and Preservation

Since their introduction to the built environment, mechanical systems and building technologies have been taken for granted. They are insulated, buried, removed from view, and expected to perform the single task expected of them. In 2012, David D. Cosner developed a report on University of Maryland's continued deferred maintenance entitled "*Invisible Crisis.*" The University of Maryland, hosting goals to achieve net zero carbon emissions by 2050, must make the state of its mechanical infrastructure a priority.

This thesis explores the power of mechanical infrastructure to propel us into a future of integrated design. Pre-existing consolidation of mechanical elements within SCUB (satellite central utility building) structures are a point of focus. New SCUB(s) act as performative infrastructural monuments, utilizing proximity of elements to increase functionality. Occupants will be immersed in the functions necessary for campus/building operations, forming a tactile connection between university occupants and their biproducts/energy usage.

INVISIBLE CRISIS

by

Gregory A Goldstein

Thesis submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Master of Architecture
2018

Advisory Committee:
Professor Karl DuPuy, Chair
Professor Brian Kelly
Professor Carl Bovill

Table of Contents

Chapter 1: University of Maryland & Net Zero

UMD's Goals for Net Zero Carbon Emissions – What is Net Zero?

Background – Energy and the Built Environment

Buildings are responsible for 40% of the United States' total energy consumption.[1] A recent response to this statistic has been a move towards net zero buildings (NZB) in an effort to reduce energy loads, carbon emissions, and environmental footprints of the quickly developing built environment. Additional benefits of net zero buildings can extend to lower operating and maintenance costs, resiliency to power outages and natural disasters, and improved energy security. As a result, an increasing number of private commercial property owners, federal government agencies, and state and local governments have begun to move towards targets of NZB in accordance with a number of regulatory mandates.[2] As we march towards this general goal of "net zero" however, we find that there are many competing factors to take into account when attempting to minimize the total footprint of a building. This footprint can be effected by the type of energy source, sourcing of materials, sourcing of labor, embodied energy of materials, construction methodology, water, waste, and much more. The extents of net zero have been debated since the genesis of the concept - we must then ask, *what is net zero*?

---

[1] *Energy Efficiency Trends in Residential and Commercial Buildings*(Rep.). (n.d.). US Department of Energy. Retrieved November 27, 2017, from https://www1.eere.energy.gov/buildings/publications/pdfs/corporate/bt_stateindustry.pdf

[2] *A Common Definition for Net Zero Energy Buildings.* US Department of Energy, the National Institute for Building Sciences. September, 2015.

Definitions and Strategies

DOE Definitions

The US Department of Energy (DOE) and the National Institute of Building Sciences worked towards establishing definitions, nomenclature, and measurement guidelines for Zero Energy Buildings (ZEB). A commonly recognized definition would have a significant impact on design strategies and market uptake for ZEB projects.[3] A result of this push towards common nomenclature, definitions were created for ZEB in association with *collections of buildings* as well. In addition, the Net Zero Building Council and Architecture 2030 launched a project to achieve net zero carbon emissions in buildings by 2050 releasing a definition for zero net carbon (ZNC) buildings.[4]

Zero Energy Building. (ZEB) An energy efficient **building** where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy.

Zero Energy Campus. (ZEC) An energy efficient **campus** where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy.

Zero Net Carbon (ZNC) A highly energy efficient building that produces on-site, or procures, enough carbon-free renewable energy to meet building operations energy consumption annually.

[3] KM Fowler, "Federal New Buildings Handbook for Net Zero Energy, Water, and Waste." *US Department of Energy*, *Pacific Northwest National Laboratory*. Retrieved November 29, 2017 from https://energy.gov/sites/prod/files/2017/08/f35/net_zero_new_buildings.pdf
[4] "Zero Net Carbon (ZNC): A Definition." (n.d.). *Architecture 2030*. Retrieved November 27, 2017, from http://architecture2030.org/zero-net-carbon-a-new-definition/

Building Energy. Energy consumed at the building site as measured at the site boundary. At minimum, his includes heating, cooling, ventilation, domestic hot water, indoor and outdoor lighting, plug loads, process energy, elevators, and conveying systems, and intra-building transportation systems.

Renewable Energy. Energy sources that are naturally replenishing but flow-limited. They are virtually inexhaustible in duration but limited in the amount of energy that is available per unit of time. Renewable energy resources include biomass, hydro, geothermal, solar, wind, ocean thermal, wave action and tidal action.

Source Energy. Site energy (same as building energy) plus the energy consumed in the extraction, processing and transport of primary fuels such as coal, oil, and natural gas; energy losses in thermal combustion in power generation plants; and energy losses in transmission and distribution to the building site.

Johnson Controls Strategies

With an established set of definitions and benchmarks, numerous strategies were developed in order to meet net zero criteria in both renovation and new construction. An 8 step plan for **renovation** was developed by the Institute for Building efficiency in conjunction with Johnson Controls.[5] These steps are as follows:

Plan ahead, build the right team, set goals. Good planning can afford building owners the ability to easily replace or expand upon existing mechanical systems without falling for common errors. This can be basing loading off of obsolete rules of thumb that may or may not apply to the building type or use. The team assembled for execution should be

[5] Cara Carmichael, Katrina Managan. "Reinventing Existing Buildings: Eight Steps to Net Zero Energy." *Institute for Building Efficiency, Johnson Controls*. May, 2013.

comprised of designers and engineers that can collaborate to design across fields with the ability to analyze use patterns to set achievable goals.

Choosing a definition of NZE: weighing definition tradeoffs. While these steps were produced before a movement for common nomenclature, this step remains quite relevant. Definition tradeoffs are mainly *where and why* energy is being produced. Will the building achieve net zero site, source, cost, or emissions energy?

Set a baseline and documents business-as-usual expenditures. In order to maximize efficiency, owners must understand their typical expenditures and how this compares to other buildings of a similar nature.

Technical potential charrette. Innovative ideas are a common product of workshops. Not only do they allow brainstorming and collaboration, but they have the ability to engage stakeholders early in the process.

Iterative modeling, design, and costing of measures. Energy modeling allows for validation of design decisions early in the design process. Occupant loads along with many other existing factors can be plugged in to provide meaningful feedback.

Phasing installation and implementation. Retrofit can be achieved at once or in phases. Phased implementation allows for adaptability with changes in load and usage, and provides an economically approachable route for owners.

Publicity (internal and external). Broadcasting achievements can help advance goals to net zero by not only increasing occupant moral and action, but also by attracting stakeholders and bettering public image.

Ongoing system commissioning and occupant behavior. The transition from design to implementation is a difficult one. Facility management must be adequately trained to maintain performance. Monitoring and commissioning is essential to meeting goals of net zero in implementation phase.

Pacific Northwest National Laboratory Strategies

Working with the US DOE, the Pacific Northwest National Laboratory developed a set of strategies for net zero in **new** federal buildings,[6] which may be easily applicable to any other building type. Goals for NZE are broken down into 3 categories: design, construction, and occupation.

Design. When approaching new building design, one must first design for a high performance energy efficient building. In this phase, elements such as siting, orientation, envelope, heating, energy recovery, etc. should be considered. The next step is modeling the new building to estimate annual source energy use. Here, optimum solutions are determined through quantifiable iterative design. The third step is designing a renewable energy system which compensates for modeled energy consumption. Lastly, the impact of design reviews and value engineering must be minimized in order to achieve net zero targets.

Construction. When beginning construction phase of net zero design, contract language must be developed to maintain the integrity of net zero goals. Installation of net zero elements is key for use – poor construction practice can lead to thermal bridging, air gaps, etc. Lastly, a commissioning plan should be developed which includes planning, assessing energy costs and savings, implementing recommendations, and integrating findings into operations.

---

[6] KM Fowler. "Federal New Buildings Handbook for Net Zero Energy, Water, and Waste." *US Department of Energy, Pacific Northwest National Laboratory*. Retrieved November 29, 2017 from https://energy.gov/sites/prod/files/2017/08/f35/net_zero_new_buildings.pdf

Operations. Upon building completion, an operational plan should be developed to address O&M (operation and maintenance) of energy efficiency design features and renewable energy technology. Descriptions of measures, action items, and frequency of action items should be included. Energy use and production must then be metered in accordance with identified performance benchmarks. Next, behavior changes and training programs should be set up to engage occupants in performance goals. Once the trajectory for net zero is set utilizing all of the above steps, operation must be measured over a one-year timeframe to ensure the new building is performing as predicted.

UMD's Goals & Strategies

In 2009, the University of Maryland issued a Climate Action Plan to cut carbon emissions. A course was set to reduce university carbon footprint 25% by 2015, 50% by 2020, 60% by 2025, and to achieve net zero carbon emissions by 2050. The university achieved its 2015 goal, preventing the production/release of over 577,000 metric tons of carbon dioxide. While a majority of UMD's energy is produced by a natural gas combustion co-generation plant, 86% additional purchased electricity was acquired from renewable sources in 2016.[7] Moving towards the lofty goal of net zero carbon emissions, the University of Maryland has employed strategies over several fields.

---

[7] Carlo Colella. "University of Maryland Climate Action Plan 2.0." Carlo Colella, *University Senate.* Retrieved November 28, 2017 from https://www.senate.umd.edu/sites/default/files/resources/MeetingMaterials/04062017/Climate_Action_Plan_2.0_16-17-30.pdf

Power. Strategies to combat carbon emissions in the front of power include enhancements to facilities, purchased renewable power, carbon neutral new development, heat and power plant improvements, behavior change, carbon capture technology, on-campus renewable energy, and increased capital investment for high performing energy efficient buildings.

Commuting. The University plans to improve fuel efficiency of commuter vehicles, additional student housing on and near campus, increased use of vanpools, introduction of purple line light rail service, increased use of carpooling, installation of more electric vehicle charging stations, development of effective transportation demand management programming plan, and improvement of bicycle connectivity between UMD and local neighborhoods.

Air Travel. The university will take air travel into account and offset any carbon emissions produced through funding of various emission reduction programs.

Solid Waste. UMD will increase recycling of solid waste, reduce solid waste generation, divert solid waste from landfills, and promote education and outreach for waste reduction.

Land Use and Maintenance. Grounds and Landscaping activities will be improved for lower carbon emissions, on-campus carbon sequestration of forests will be quantified, and campus tree canopy will be increased.

Purchasing. Sustainable food purchasing will be installed as a practice, sustainability language will be added to procurement procedures and mechanisms, compliance with environmentally preferable procurement policies will be achieved, and vendor contracts will be augmented to include sustainable procurement policies.

Education and Research. First year undergraduates will be educated on sustainability while integrating sustainability across curriculums, active learning programs and research on sustainability and climate change will be fostered, new sustainability degrees will be offered, research sustainability funds will be offered, and research technologies will be deployed on campus.[8]

Additionally, an energy task force comprised of key facility management personnel was developed. This task force developed a utility dashboard displaying the footprint of campus over a broad spectrum including carbon emissions, energy usage intensity, chilled water use, steam production, and cost of operations.[9] This allows operations to be cross referenced with existing operational benchmarks. As a reference, Energy Star created a list of median energy usage intensity (EUI) values to serve as benchmarks for operation.[10] Energy Star sites typical site EUI of College/University buildings to be 130kbtu/sqft. Of the 177 buildings with quantified performance, 35 have an EUI ranging from 130 to over 450 kbtu/sqft. (fig. 1)

[8] For more information on University of Maryland's plan for net zero carbon emissions by 2050, visit https://sustainability.umd.edu/progress/climate-action-plan-20.

[9] "University of Maryland Utility Dashboard." *UMD Facilities Management*. Retrieved November 30, 2017 from http://terpfootprints.umd.edu/

[10] "US Energy Use by Property Type". Energy Star. March, 2016.

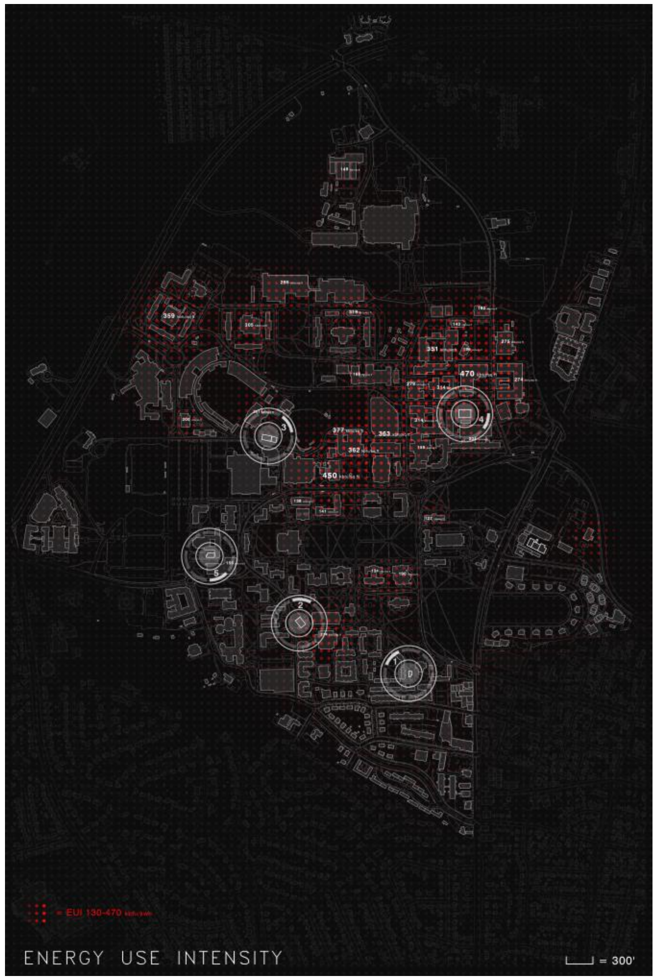

Figure 1- Campus EUI (energy usage intensity) (Source: Greg Goldstein)

Technical Considerations

Mechanical Systems

Much of UMD's power supply and the entirety of its steam supply is sourced from the cogeneration plant located on Baltimore Ave. (rt 1) and Rossborough Ln. This plant hosts a pair of 10.5 megawatt natural gas combustion turbines in conjunction with a pair of heat recovery steam generators totaling 280,000pph steam production. As of June 2012, the peak electrical load of campus totaled just under 50 megawatts with a peak steam load of 245,000pph.[11] While the plant is experiencing wear such as corrosion in boilers, the system is relatively efficient in its duel functionality. (fig 2)

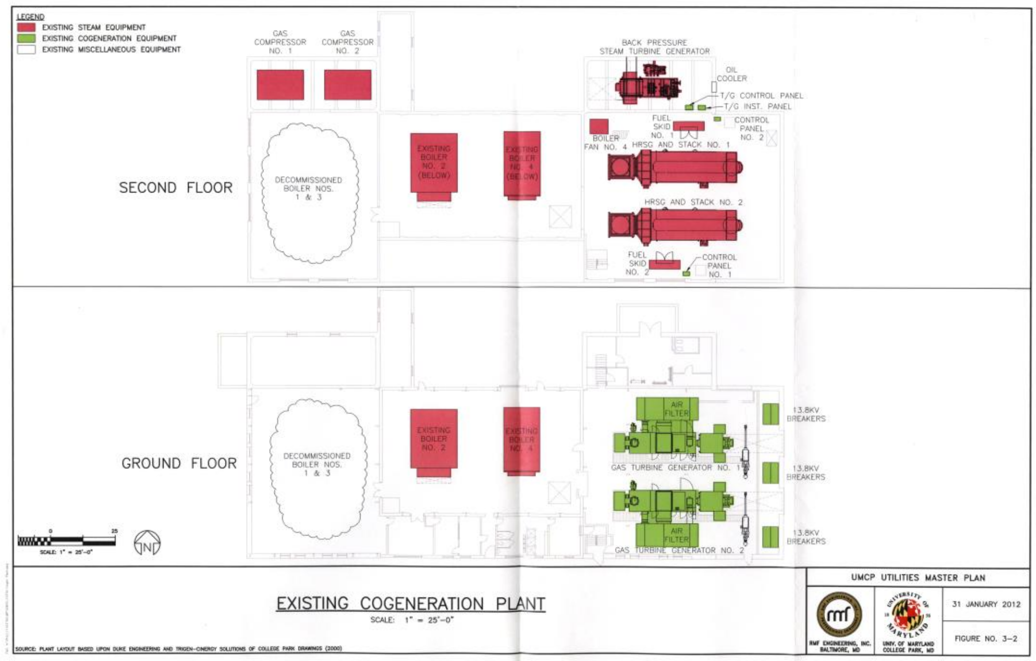

Figure 2- Layout of Cogeneration Plant. (Source: RMF Engineering, CDM Smith Group. "UMCP Facilities Master Plan.". University of Maryland, College Park, *(2012).)*

Campus heating and cooling systems are localized in units referred to as SCUBs (satellite central utility building). These SCUBs contain equipment for heating and cooling of water and serve to channel and distribute steam from the campus' cogeneration plant. Considering the plant's peripheral location relative to campus, these SCUBs are employed to extend the range of steam through water. Equipment and function of each SCUB can vary based on buildings served and

---

[11] RMF Engineering, CDM Smith Group. "UMCP Facilities Master Plan.". *University of Maryland, College Park,* (2012).

location – all contain water chiller units of varying type, however SCUBs 1 and 2 provide direct hot water service whereas SCUBs 3 4 and 5 provide steam to water and/or direct steam services to buildings served. According to facility management, much of the equipment in these SCUBs have reached the end of their usefulness having become difficult to maintain, and relatively inefficient.[12] As SCUBs 1-5 represent units in which several infrastructural systems throughout campus are consolidated within an independent devoted structure, they are the intended point of departure and focus for this thesis. (fig 3)

Figure 3- SCUB 1-5 parabolic layout about cogeneration plant. (Source: Greg Goldstein)

---

[12] David D Cosner Sr. "Failing Infrastructure Creates Invisible Crisis at University of Maryland." *University of Maryland, College Park*, (2012).

When proposing infrastructural solutions, a masterplan must be taken into account. Piped distribution systems are designed to start large from their source and terminate small towards their destination.[13] If an existing distribution system is to be taken into account, a new SCUB must be located along its largest distribution line.

Management

Campus utilities are currently overseen by University of Maryland Facilities Management (FM). UMD FM is currently comprised of 800 employees and falls under the administrative umbrella of the associate vice president. Operation of the campus's cogeneration plant, steam distribution system, and SCUB 4 is currently contracted to Suez Energy. This private – public partnership was initiated in 1999. The contract ends in 2019, at which point UMD is considering alternatives. Though the contract came with $71 million in new equipment, there remained a large backlog in maintenance which has increased to this day. The current estimate is $133 million in immediately required repairs including but not limited to leaking steam and water lines, damaged foundation drain systems, outdated emergency power systems, unreliable/unsafe electrical gear, and corroding sprinkler lines. (Cosner, 2012) Discrepancies in contractual obligations lead to confusion regarding responsibility, and maintenance continues to be deferred.

Unfortunately, Facilities Management operates under the same capital budget as every other initiative at University of Maryland. State allocated funds are limited, and most major projects completed are the product of generous donors. Within this system, donors favor projects with a clear impact on the public realm – it is not

[13] Jack Baker. Interview by author. University of Maryland Service Building. March 8th, 2018

common for a private donor to accommodate a service building outside the realm of public-private partnership.

Chapter 2: Infrastructural Architecture

Approaching the University of Maryland through the lens of architectural design, it is imperative that we first view it as *urban* – as a collective built environment. Aldo Rossi, describing the architecture of the city, stated:

"*…the city [is] seen as a gigantic manmade object, a work of engineering and architecture that is large and complex and growing over time.*"[14]

This is particularly true of our context – though the authorship of the campus is plural, its design and control has been in the hands of a single governing body. This fact opens many possibilities in the realm of infrastructure. Systems are typically ruled by various political tensions, separated and buried. When analyzed as a series of inputs and outputs, infrastructural systems have the ability to benefit each-other when flows are composed under the auspices of *design.* Architecture has the unique ability to act as the mediator between these various flows. The concept of *infrastructural architecture* has been expanded upon and developed over the last century by various architectural theorists.

[14] Aldo, Rossi. "The Architecture of the City, trans. Diane Ghirardo and Joan Ockman" *Cambridge, MA: MIT Press,* (1982), 29.

Relevant Scholarly Topics: Infrastructural Architecture

Corbusier

Radiant city is perhaps the first glimpse of infrastructural architecture as we come to understand it today. Le Corbusier's approach to "the city of the future" was radical for its time, and captured the essence of architecture as mediator between flows at the scale of a city. Endorsing verticality, Corbusier's intent was a dense yet virtuous city center allowing shorter distances to be covered by traffic and services. Believing that the current concept of the street was outdated, he endorsed the idea of consolidating systems within an accessible framework – layering the city to accommodate for various functions. (fig 4)

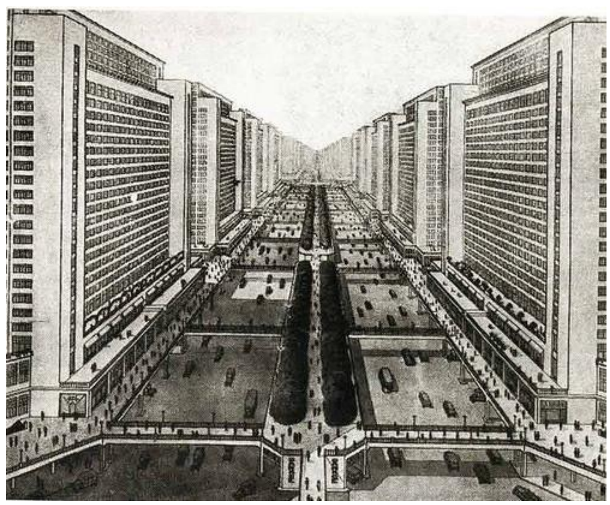

Figure 4- Corbusier's Radiant City. (Source: Archdaily.com)

In Corbusier's *Plan for Algiers,* these layers were consolidated into a curvilinear datum resembling a large wall. This wall mediated equitable access to light and air while providing a framework for consolidation of various flows on the city scale. (fig 5)

Figure 5- Corbusier's Plan for Algiers. (Source: Le Corbusier, Plan Obus A, Algiers, photomontage, 1931–32 (Le Corbusier, La Ville Radieuse [Paris: Éditions de l'Architecture d'Aujourd'hui, 1935], 236, Fondation Le Corbusier, Paris, FLC L1-1)

James Corner

In James Corner's article *Terra Fluxus*, the line between landscape and built environment is interrogated. The concept of urban surface is explored:

"…*I would emphasize a second understanding of surface: surface understood as urban infrastructure. This understanding of the urban surface is evident in Rem Koolhaas's notion that urbanism is strategic and directed towards the 'irrigation of territories with potential.' Unlike architecture, which consumes the potential of a site in order to project, urban infrastructure sows the seeds of future possibility, staging the ground for both uncertainty and promise.*"[15]

Corner expands upon the fluid nature of processes on the urban scale – as opposed to *terra firma*, a static definition of surface, he speaks to a *terra fluxus* – a surface allowing flexibility and exchange between complex processes. This idea is expanded upon in Corner's proposal *Urban Metabolism, Rotterdam*:

[15] James Corner. "Terra Fluxus." *Terra Fluxus. Lotus International*. 2012.

"*...look for the synergy between the various flows by linking them to each other at the local level or by making more exchanges between flows. Spatial design can make a significant contribution to this by creating the preconditions for combining flows and improving the way they relate to eachother.*"[16]

Rem Koolhaas

Perhaps the most prominent voice regarding urban flows in its relation to architecture, Rem Koolhaas heavily endorses the concept of exchanges and flows in nearly all his work. This understanding of flows gives way to a vast spectrum of design possibilities where architecture serves as a medium, or catalyst for intricate intersections.[17] Koolhaas' layered approach to urbanism speaks to the complexity of urban fabric and the processes which it entails.

"cities are reaching a new scale and a level of organization where architecture has to recede in terms of its claims. Infrastructure is much more important than architecture."[18]

Stan Allen

In his book *Points and Lines*, Stan Allen's argument towards infrastructural urbanism is crystalized. Arguing that architecture in the urban fabric has become

[16] James Corner. "Urban Metabolism, Rotterdam." *Rotterdam, Netherlands. Mediacenter Rotterdam.* 2014.
[17] Gilles Delalex. "Go With the Flow: Architecture, Infrastructure and the Everyday Experience of Mobility." *Gummerus Printing, Vaajakoski, Finland.* 2006.
[18] Koolhas, Rem. "The NS Interview: Rem Koolhaas, Architect." Interview by Samira Shackle. *New Statesman* May 2012. Retreived 12/7/17 from https://www.newstatesman.com/culture/art-and-design/2012/05/ns-interview-rem-koolhaas-architect

perhaps too representational, the idea of an architecture of instrumentality is promoted.

"…while architects are relatively powerless to provoke the changes necessary to generate renewed investment in infrastructure, they can *begin to redirect their own imaginative and technical efforts toward the questions of infrastructure. A toolbox of new and existing procedures can be expanded by reference to architecture's traditional alliance with territorial organization and functionality."*[19]

At MIT's *Infrastructural Monument* conference, Stan Allen continued to expand on the idea of infrastructural urbanism.

"What is required is a new mindset that might see the design of infrastructure not as simply performing to minimum engineering standards but as capable of triggering complex and unpredictable urban effects in excess of its designed capacity."[20]

Infrastructural systems, since their introduction to our built environment, have been largely taken for granted. They are insulated, buried, removed from view, and expected to perform the single task expected of them. An association, however, between occupants and their biproducts has the capacity to enrich the urban experience.

<u>*Precedents*</u>

Amager Bakke by BIG architects is a recent waste to energy plant in Copenhagen. The tallest and largest building in the city, the plant hosts a ski slope in

[19] Stan Allen. "Points and Lines." *Princeton, NJ. Princeton University Press*. 1999.
[20] Stan Allen. "Infrastructural Monument." *Cambridge, MA. Princeton Architectural Press*. 2016. P 56

contrast to its utilitarian purpose. As opposed to simply exhausting fumes from incineration, the plant releases smoke "doughnuts" for every ton of waste incinerated. Not only does Amager Bakke represent a fusion of architecture and infrastructure in a tasteful manner, but it demonstrates an excellent opportunity to establish a tactile relationship between waste flows/processes and their users, the people of Copenhagen. (fig. 6)

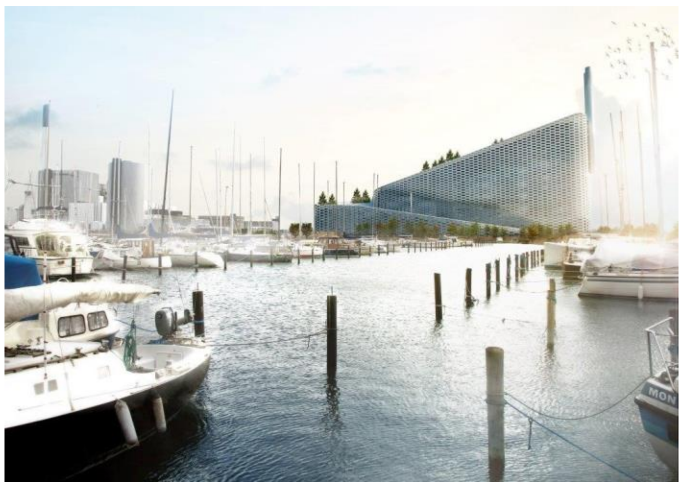

Figure 6- Amager Bakke. BIG architects. Copenhagen. Incinerator/ski slope emits smoke rings to transmit waste metrics (Source: Archdaily.com)

The **Ohio State East Regional Chilled Water Plant** by Leers Weinzapfel Associates represents a significant investment by the Ohio State University. Housing chiller units and cooling towers for east campus, the plant both acts as a threshold to the campus and frames an adjacent park, providing indirect lighting at night. The housing for chiller units is a frosted glass, allowing a degree of transparency to the university’s infrastructure. The cooling tower envelope is composed of a light perforated metal screen for ventilation. (fig. 7)

Figure 7- Ohio State East Regional Chiller Plant. Transparency. (Source: Archdaily)

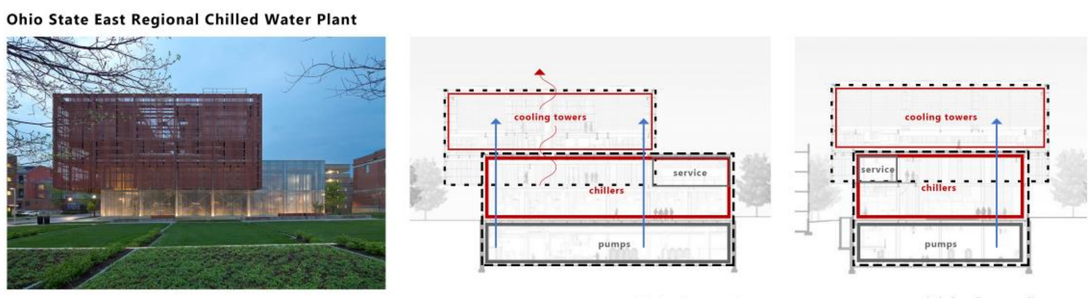

Figure 8- Sectional Analysis, Ohio State East Regional Chilled Water Plant. (Source: Greg Goldstein)

The **Ohio State South Campus Chiller Plant** by Ross Barney Architects is composed of a steel skeleton and modular concrete shell. The nature of this shell allows for expansion, while a regular modular glazing unit is flipped multiple ways to compose irregular openings. This plant provides chilled water to the southern quadrant of Ohio State University, housing chillers and cooling towers. Views of the equipment are framed by aforementioned irregular openings, broadcasting the function of the unit to its surroundings. Glass fins render the surface a variety of colors over the course of the day, conveying movement.[21] (Fig. 9)

[21] “OSU South Campus Chiller Plant.” 2013. Ross Barney Architects. Retrieved 12/10/2017 from http://www.r-barc.com/wp-content/uploads/2013/01/OhioStateUniversitySouthChiller.pdf

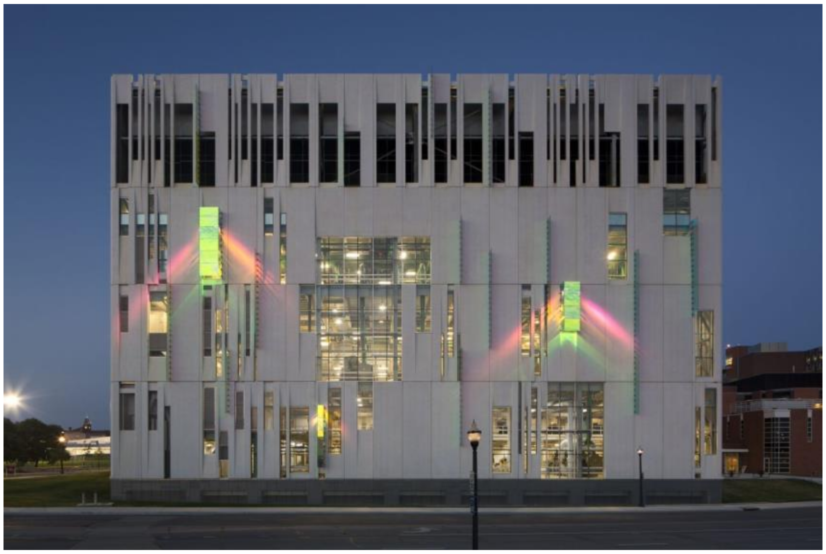

Figure 9- Ohio State South Campus Chiller Plant. Glass panels project light on surface, conveying movement. Ross Barney Architects. (Source: Archdaily)

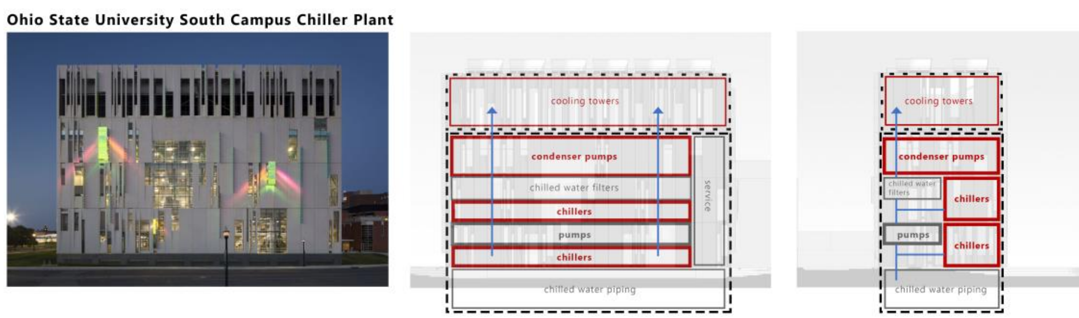

Figure 10- Ohio State University South Campus Chiller Plant Sectional Analysis. (Source: Greg Goldstein)

Urban Metabolism, Rotterdam was a joint effort between James Corner/Field Operations and the municipality of Rotterdam. Rotterdam's metabolism, or processes regarding the function of the city, were mapped and proposals were formed based off of this investigation. Flows were analyzed on an urban scale, and design proposals were created to maximize on these flows through architectural design. The product was comprehensive, offering solutions ranging from optimal water landscape designs to sedimentation of riverbeds for oyster growth. (fig. 11)

Figure 11- Urban Metabolism, Rotterdam. Aerial view. Source: Urban Metabolism, Rotterdam. *(2014) James Corner. Rotterdan, Netherlands. Mediacenter Rotterdam*

Chapter 3: Design Approach

Program

Mechanical Consolidation and Performance.

University of Maryland's SCUB units represent an excellent opportunity for employment of infrastructural architecture. Typically, infrastructural systems operate in isolation. Outputs of these systems, too often becoming waste, have the ability to effect the performance of other operations positively within the system. In her book *The Works, Anatomy of a City*, Kate Ascher expands on the idea that connections between forms of infrastructure should become more routine.[22] For a truly sustainable future, we must begin to make the most of resources given to us. Through spatial coordination and planning, architecture has the capacity to shape the preconditions necessary to truly utilize effluents and flows of currently existing systems. The same

[22] Ascher, K., & Marech, W. "The works: Anatomy of a city." *New York: Penguin Press*. 2005.

may be said for University of Maryland's SCUBs. By capturing waste processes, the efficiency of systems on campus may be increased - this has the capacity to lower carbon footprint by requiring less site/source energy input while consolidation lessens staffing requirements and allows for ease of maintenance/monitoring.

Site Specific Additions

SCUBs have the opportunity to host site-specific program. While on a basic level they may operate as "museums for mechanical artifacts," they should have the ability to engage the public realm on a tactile level.

SCUB 4 currently hosts offices for facilities management. However, these offices are used by staff with no affiliation to maintenance and operation of the SCUB while necessary staff are housed off-site. New SCUBs should be programmed with offices supporting maintenance and operation.

Pending relation to processes on campus, new SCUBs may host a large variety of additional program. Near dining halls for example, anaerobic digestors may be utilized to decompose food waste for generation of fertilizer and methane gas for power. Algae photobioreactors utilize nitrogen and phosphorous off-gasses from these units, and may be programmed within new SCUBs to produce substrate for bio-diesel or produce energy. Study spaces can be incorporated, as well as cafés or retail when isolated from campus social centers.

Education & Integration

Education on sustainability is a primary goal for University of Maryland in their Climate Action Plan. (Colella, 2017) With this in mind, it is important to utilize new SCUBs as an educational tool. New SCUBs will educate students through immersion in systems necessary for the operations of the university while facilitating additional education specific to fields that will benefit the most from mechanical program. These fields include all degree programs within MAPP+D, landscape architects, as well as mechanical and civil engineers. An on-site workshop can give architecture students the ability to fabricate mock-up building assemblies while "plug and play" laboratories give engineering students the opportunity to test mechanical systems on both building assemblies and campus' infrastructural grid as a means to drive integrated design and collaboration in the design fields.

Conceptual Design

SCUB Strategies

Following a comprehensive study of SCUBs & infrastructure on campus, three new classes of prototypical SCUB facility (A,B &C) were designed, and a series of possible site locations were determined. The prototype and new sites represent the ideal condition – this was then cross referenced with the circumstantial to produce a final proposition. These prototype models organize infrastructural elements within to both passively and actively maximize waste recovery & performance while serving as interactive visual indicators for energy use/consumption. Key considerations in design are **performance/expandability**, **maintenance**, **transparency**, **accessibility/security**, **public engagement/interaction**, and **aesthetics**.

Performance is a root of this thesis. To retain viability, new SCUBs must demonstrate a benefit in both efficiency and cost. A highly efficient infrastructural system, defined as requiring minimal input for maximum output, has the ability to push the university towards its goal of net zero carbon emissions. This became the primary driver behind design.

In order to maximize efficiency of SCUB operations, a stacked concept was developed. This affords the structure the ability to capture and re-use rising heat while offering the ability to quickly evacuate excess heat. A modular approach to the stacked concept allows for the potential to **expand** as campus needs increase rather than rebuilding or constructing more SCUB units. Steam pipes are routed from below with heating elements and thermal chimney above. Chillers are adjacent to heating elements to utilize cool effluent and in turn provide hot effluent to heating elements. Cooling towers are above chillers and adjacent to the thermal chimney. Energy Modeling was applied to conceptual form variations to study the effect of form on passive solar accumulation. Orientation is of course key; a broad south face catering to heating elements is heavily glazed while utilizing photocatalytic cement as thermal mass. This photocatalytic cement is self - cleaning, and through a titanium dioxide added to the casting process has the ability to turn phosphates and nitrates found in air into salts via passive solar reaction. With every rain, salt water may be collected through a rill at the bottom of the face. The brine is utilized within ice tanks in the facility to prevent fluid from freezing.

Maintenance was clearly one of the largest dilemmas facing SCUBs. A product of several degrees of separation between monitoring staff and equipment, easy problems typically become either blown out of proportion or swept under the carpet. A major design goal became increasing the **transparency** of SCUBs in order to counteract what has been coined as the “invisible crisis” in facility management’s report bearing the same name. (Cosner, 2012) Units requiring the most maintenance (chillers/heating units/steam pipes) receive the highest degree of transparency.

Figure 12- SCUB 3. Oct 27th 2017. (Source: Greg Goldstein)

Accessibility/security becomes important when dealing with consolidated infrastructure for a university entity. While the SCUBs maintain a degree of transparency, they must also be highly secure. In addition to contextual considerations, entries will be limited and highly visible. Currently, all SCUBs are positioned on drastic changes in topography. This allows the basement levels to be exposed/accessed, and provides an easy route for subterranean infrastructure to enter. This was applied as a necessity in the site selection matrix.

Public engagement is central to the project. Systems in isolation are seldom considered – in order for the University of Maryland to achieve its goals of net zero carbon emissions, an awareness of energy goals must be shared. It was therefore key to provide SCUBs a way to form a tactile relationship between campus occupants and energy use metrics. The generation of heat, or more specifically the exchange of heat, has the ability to make itself present in different ways to accommodate this. Locations of steam and/or water lines can be made evident through landscaping design to provide users with further layers of understanding.

Aesthetics are important to consider given the established sense of *place* at the University of Maryland. It is necessary to articulate SCUBs as different then surrounding buildings in order to satisfy the parameters of transparency and public engagement in conjunction with SCUB program, however SCUBs must not feel foreign to the campus. Scale of building materials and orders must be taken into consideration, along with the prevailing architectural language of campus – commonly accepted as colonial revival.

Site Analysis

Methodologies

A set of criteria were formed for selection of ideal SCUB sites to be vetted by circumstantial conditions. Data provided by University of Maryland Facilities Management [23] [24] was mapped in conjunction with existing SCUB conditions. This criteria is composed of the following:

1. **Proximity to Campus Buildings**

   How many buildings are in each site's immediate vicinity? What is the proximity to current SCUB's served buildings? A site with a higher demand or necessity justifies more attention than a site with lower demand. (Fig 13)

[23] University of Maryland Facility Management. "Utility Assessment." *College Park, MD. RMF Engineering.* 2012.
[24] University of Maryland Facility Management. "UMCP Utilities Masterplan." *College Park, MD. RMF Engineering.* 2012.

Figure 13- SCUB buildings served, detailed service breakdown. (Source: Greg Goldstein)

2. Proximity to Energy Intensive Buildings

As each SCUBs design will be affected by the buildings it serves, what are potential/existing site's relationships to campus structures with high EUI? More importance may be attributed to a SCUB with higher demand.

3. Proximity to Social Hubs

What is the proximity of potential/existing sites to social centers and/or high traffic zones? This has a direct correlation to how successfully each SCUB will propagate public interaction. (Fig 14)

Figure 14- social hubs. (Source: Greg Goldstein)

4. Relationship to Current/Projected Steam/Water/Powerlines

What is each potential/existing site's relationship to existing/projected steamlines/chiller/power infrastructure? The state of current infrastructure may inform the validity of sites around campus. The necessity for line replacement can serve as the impetus for laying new lines for new sites or vice versa. (fig 15, 16)

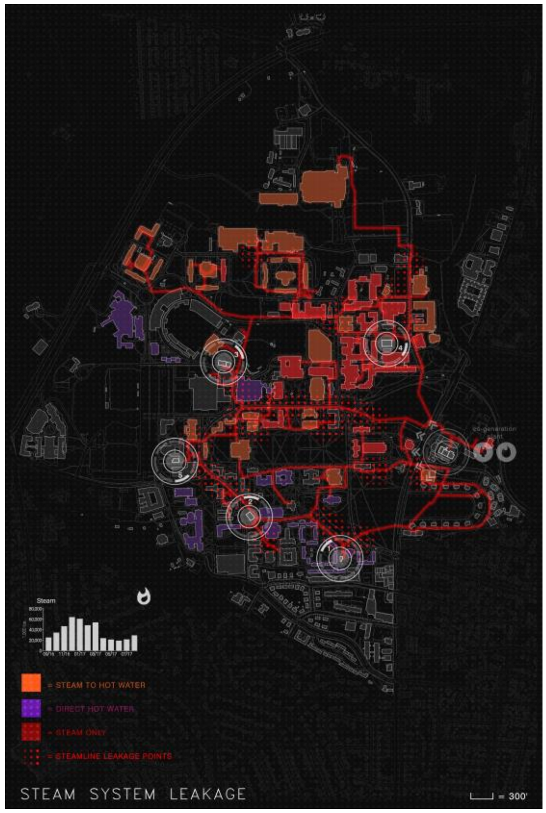

Figure 15- Campus steam usage. (Source: Greg Goldstein)

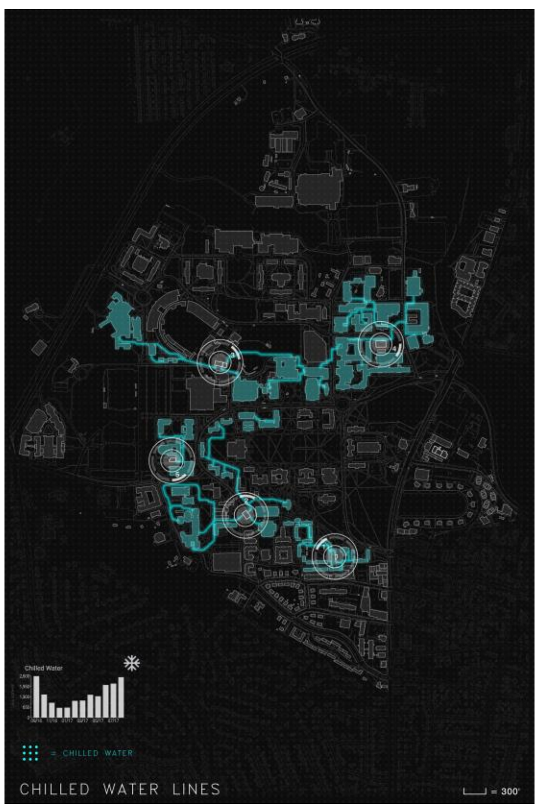

Figure 16- Campus chilled water lines. (Source: Greg Goldstein)

5. Relationship of Site to Campus Layout (SCUB as Urban Response)

How does each existing/potential site engage the current campus, and how do they engage the projected masterplan for 2030? (fig 17) Every addition to campus inevitably changes the fabric – what this change entails must be heavily considered in site selection. The addition of the purple line through campus and how new SCUBs engage the train along with its stops is quite important as well. (fig 18)

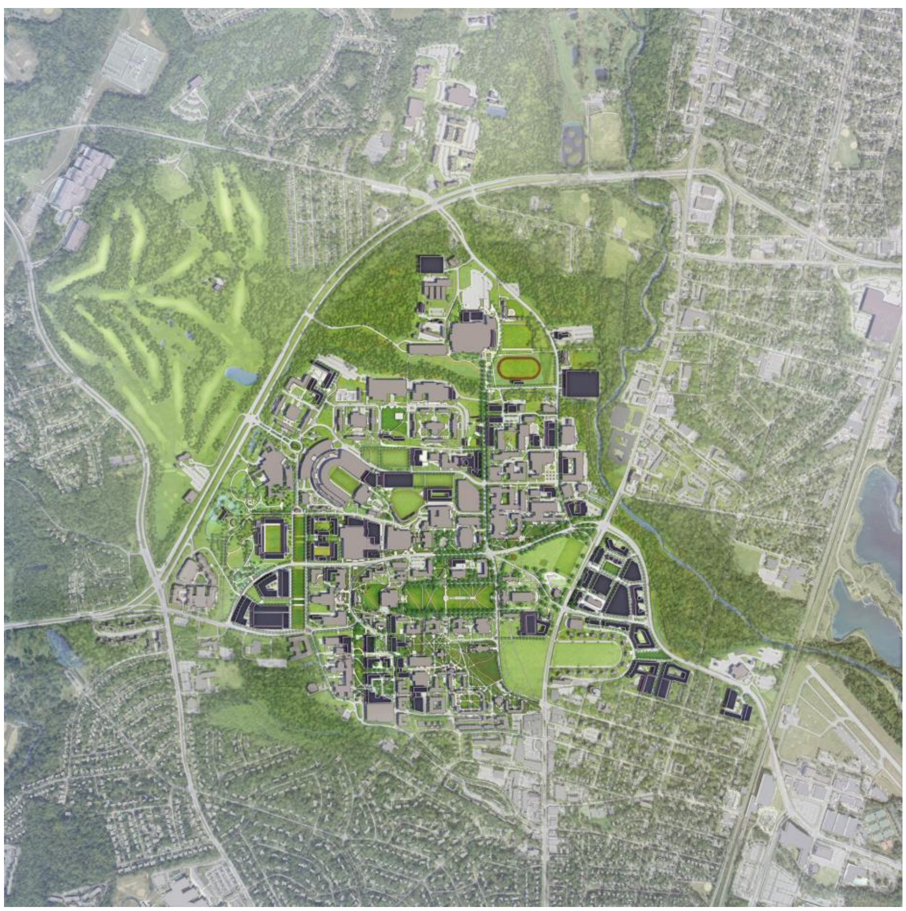

Figure 17- Campus Masterplan – 2030. Design Collective. (Source: http://www.designcollective.com/portfolio/project/university-of-maryland--facility-master-plan/)

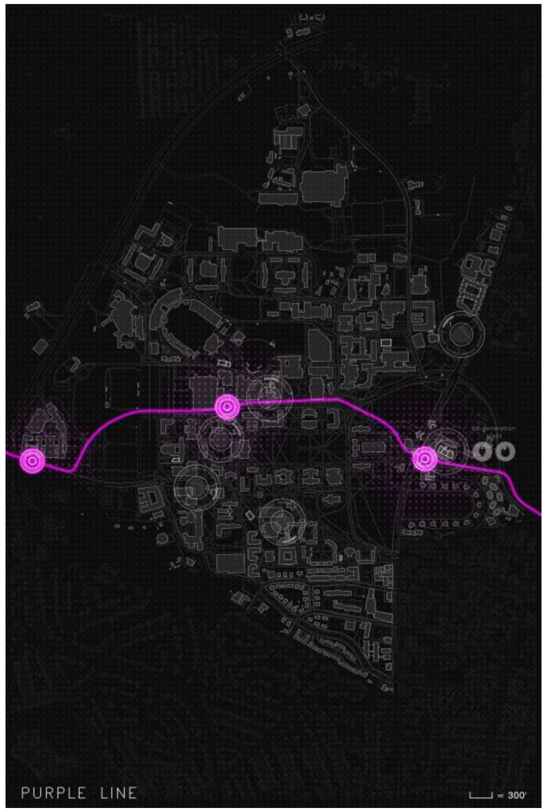

Figure 18- Projected Purple Line through campus. (Source: Greg Goldstein)

6. Preferable Topographic Conditions (Substantial Grade Change)

Locating SCUBs on a site with substantial grade change is beneficial to SCUB function. (Fig 19) Not only is this a natural point to access subterranean infrastructure, but it also allows for basement level access to access/insert/remove heavy, bulky machinery/equipment.

Figure 19-UMD topographical conditions. 2ft contours. (Source: Greg Goldstein)

Both the 5 existing SCUB site locations and 5 ideal SCUB locations were determined and mapped. (fig 20) The above selection criteria was applied to each in the form of a matrix. (fig 21) For existing SCUB locations, selection is affected by the current state of steam/chiller lines, walk score, buildings served, proximity to social centers, date of construction, size, cost, and capacity. While current steam/chiller lines, walk score, buildings served and proximity to social centers could be applied to the selection matrix of *ideal* sites, size, cost, and capacity could not. Instead, proximity to the new purple line was included in ideal site selection. Walkability was determined from walkscore.com, taking distance to urban venues/transit into consideration. Data regarding date of construction, size, cost, and buildings served was gathered from University of Maryland Facility Management and ranked linearly. University of Maryland’s “Energy Dashboard” acted as a source for real-time energy use intensity data, and campus buildings with an EUI over 130 were counted within a radius of 1000’ of each SCUB site. Dining halls and recreation facilities were utilized as “social hubs,” and the same 1000’ radius was applied to determine how many were considered within range of each site. Once data for each category was recorded, SCUBs were ranked linearly 1 through 5. No weights were applied to categories during the ranking process.

Figure 20- ideal SCUB locations. (Source: Greg Goldstein)

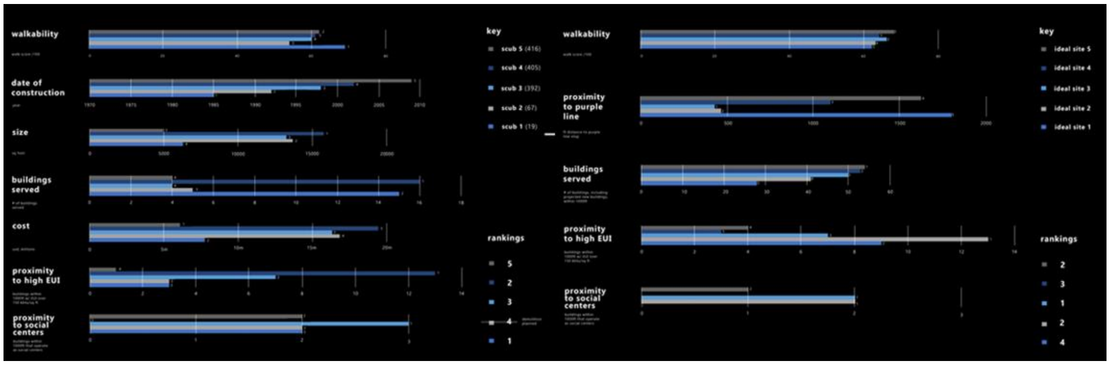

Figure 21- Left: existing SCUB selection matrix. Right: ideal SCUB site selection matrix. (Source: Greg Goldstein)

Conclusions

Existing sites. SCUB 1 ranked highest within the existing site selection matrix as a candidate for focus. Built the earliest while remaining the cheapest and smallest to replace, the SCUB is located relatively close to on and off campus amenities and adjacent to a large amount of campus buildings for service. SCUB 4 ranked 2nd. While SCUB 4 services the energy intensive steam district on campus along with the most buildings, its cost and recent construction date make it less desirable to replace/renovate. SCUB 5 ranked lowest with the least adjacent buildings, newest construction date, and high cost for replacement.

Ideal sites. Ideal site 3 ranked the highest within the ideal site selectin matrix. Located at the center of campus adjacent to the planned purple line stop, the site has the capacity to service a large number of buildings while remaining in close proximity to social centers to engage the public. Sites 2 & 5 tied for second. While sites 2 & 5 share many similarities to site 3, they had less buildings within a 1000 ft radius and were located further away from local amenities then site 3. Site 1 ranked lowest with its relatively remote location.

Compare/Contrast. While ideal sites represent an opportunity to bring campus infrastructure to the forefront, questions of embodied energy, cost of construction, and impact must be called to question. Many current SCUBs have been built recently and represent a significant university investment. SCUBs 4 and 5 are the newest and together represent an investment of over $25 million. SCUB 2 is planned to be phased out (Utilities Master Plan, Table 2-1).

According to the site selection matrix, ideal sites 2, 3, and 5 represent the greatest opportunity on an unweighted scale. Due to their prominent location, proximity to the new purple line, and ability to accommodate for extra program from adjacencies, ideal sites 2 and 3 were favored. Located along a heavily dilapidated steam/water corridor, these sites would also set the ground for local infrastructural improvements.

Site Selection

Taking into account the existing plan to phase out SCUB 2 along with capital investments in newer SCUBs, the district served by SCUB 2 became a point of focus. As the University Master Plan currently proposes the addition of a Public Protection and Security Research building on the current location of SCUB 2,[25] ideal sites 2 and 3 were examined for their potential to accommodate current loads serviced by SCUB 2. With its proximity to a 10” water main serviced by SCUB 2 as well as major steam

[25] University of Maryland Facilities Master Plan 2011-2030. Retrieved 5/17/2018 from https://www.facilities.umd.edu/documents/fmp/2011-2030%20facilities%20Master%20Plan.pdf

lines routed about McKeldin Mall, ideal site 3 was chosen as the final location for this thesis.

Site Considerations

The first major consideration approaching the site was McKeldin Library. Designed by Henry Powell Hopkins and Allan Burton and constructed in 1958[26], Mckeldin Library sits proudly at the center of McKeldin Mall on UMD's campus. Its addition, constructed in 1993, (MAC to Millenium, 2018) forms an edge to the east end of the site. Across the rear of McKeldin Mall, approximately 400' away, lies Anne Arundel Hall. To the South sits Queen Anne's Hall, while Dorchester Hall lies to the North. Protruding nearly 80' from the ground with narrow slit windows, McKeldin's addition creates a scale unwelcome to pedestrian activity. It remained quite important to mitigate the scalar issues of McKeldin's West elevation in order to create a successful quad.

Figure 22- McKeldin Library Addition, West Elevation. (Source: Greg Goldstein)

[26] MAC to Millenium. Retrieved from http://www.lib.umd.edu/ARCV/macmil/index.html 5/18/2018.

Topographic conditions present both an opportunity and an issue. While significant slope allows the potential for access above and below grade, it presents a pedestrian issue – in this case, one must go down to go up. From East to West, grade slopes down from Anne Arundel Hall by 30 ft. North to South from Dorchester Hall, grade drops by 27 ft before raising 12 ft to Queen Anne's Hall. On an urban level, a design goal was to respond to this topography by bridging these grade changes for easy pedestrian traversal.

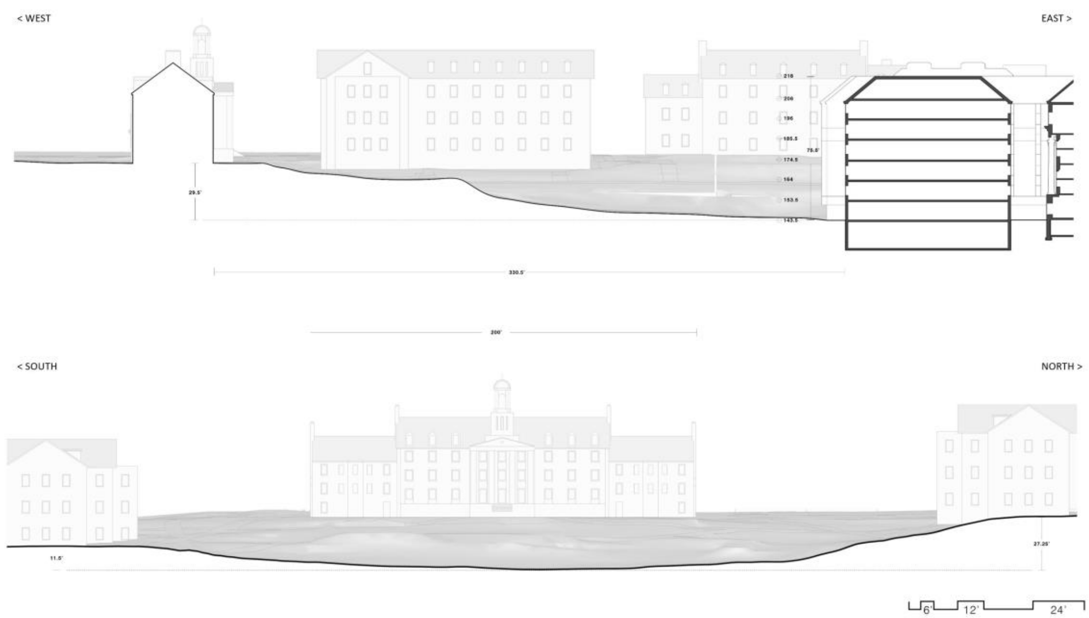

Figure 23- Topographical Conditions & McKeldin Spot Elevations. (Source: Greg Goldstein)

The site's proximity to the purple line and centrality to pertinent schools made access a motivator when composing the initial design. It was necessary to propagate movement both North and South to channel flows from the proposed train stop location, and East and West to reactivate McKeldin Library.

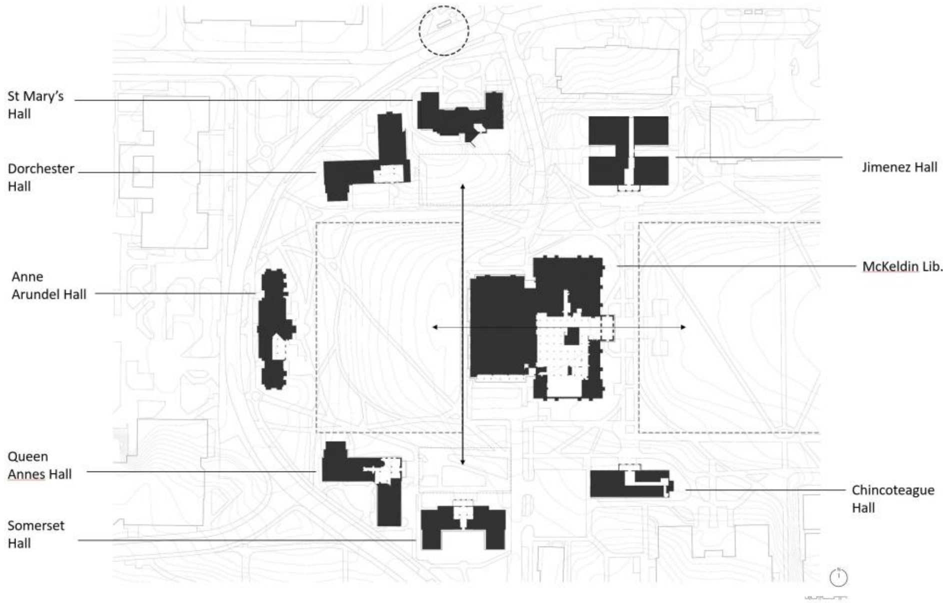

Figure 24- Site Analysis Diagram/Nolli. (Source: Greg Goldstein)

Chapter 4: Final Proposition - MSID

Program

Additional to the program of SCUB, this thesis proposes the establishment of a new integrated design program. The programs together would form the Maryland School of Integrated Design, or **MSID**. With the chosen site's adjacency to McKeldin Library and location central to MAPP+D, Business, Landscape Architecture, and Engineering district, MSID has the ability to provide a central location in which siloed disciplines may exchange their knowledge. It became the intent to disperse SCUB program through the building in order to immerse all design players in issues key to efficiency and sustainability.

MECHANICAL	7000 sq ft	WATER CHILLERS (7500 ton capacity)
	5000 sq ft	STEAM TO WATER HEAT EXCHANGERS (70,000,000 btu capacity)
	7000+ sq ft	COOLING TOWERS (+ expansion room)
	11000 sq ft	PUMPS, FILTERS, COMPRESSORS, ELECTRICAL, AIR HANDLERS
EDUCATIONAL	2520 sq ft	PLUG AND PLAY TESTING
	8300 sq ft	COLLABORATIVE STUDIOS
	3000 sq ft	WORKSHOP
MISC	1000 sq ft	CONFERENCE ROOM
	1500 sq ft	AUTOMATIONS CONTROL
	4000 sq ft	ATRIUM
	50000 sq ft	**TOTAL**

Figure 25- Program. (Source: Greg Goldstein)

Masterplan

Adapting a proposal from the 2012 UMCP utilities masterplan, phase 1 of the proposed masterplan proposes a new SCUB serving SCUB 2's current district. New buildings along Mayer Mall will be incorporated in the district, upgrading the current water distribution from a 2 pipe to 4 pipe system. The current 2 pipe system provides either hot or cold water at one time, making seasonal transitions difficult. Phase 2 and 3 of the masterplan upgrade SCUBs 4 and 1 respectively. Sizing of units was adapted from the UMCP utilities master plan. Loads were estimated to be 7500 cooling tons for water chilling and 70,000,000 btu hot water production.

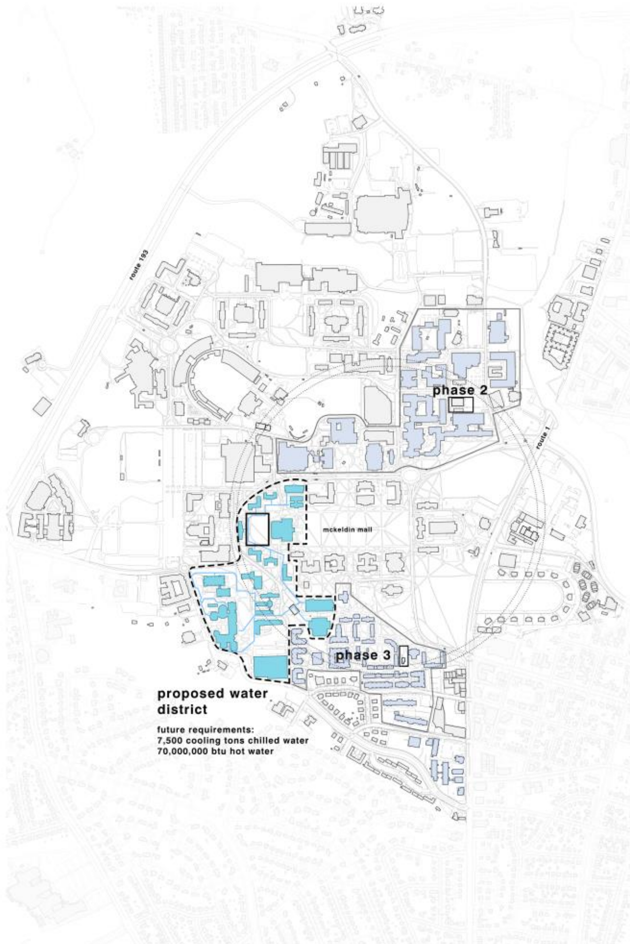

Figure 26- Proposed Water District. (Source: Greg Goldstein)

Design Exploration

Before determining the form of MSID, a series of iterative studies were performed. Of these, 3 studies were selected to expand upon: a “Head & Tail” scheme, a “Graft” scheme, and a “Gateway” scheme.

Head & Tail focused on masking the western elevation of McKeldin with a northern oriented slender bar of mechanical units (tail) while educational functions took place in a larger bar oriented West (head). The residual zone between the new structure and McKeldin would be used for service and maintenance while a gently sloped path would connect topographies to the North and South.

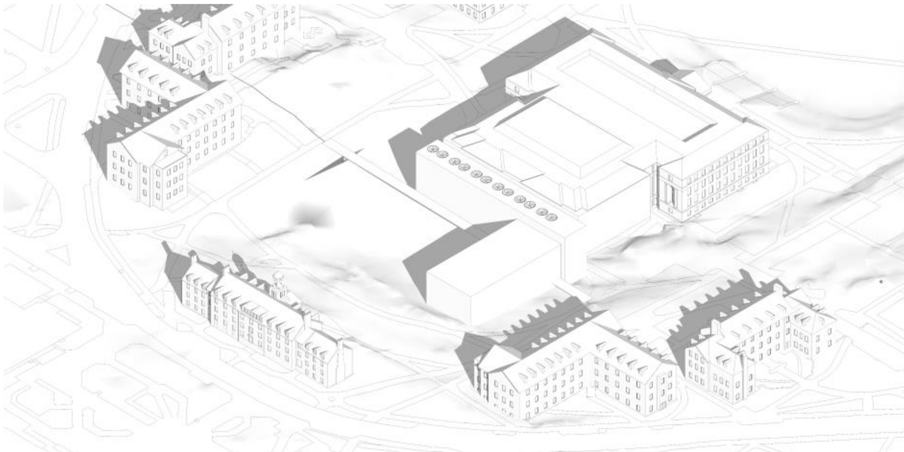

Figure 27- Head & Tail. (Source: Greg Goldstein)

Graft scheme focused on the formation of a smaller – scale quad west of McKeldin library while facilitating maximum connection between MSID and the library. A path could once again be found on the west end connecting North to South attempting to activate the new quad while a wall or screen protected educational program from intrusive western sunlight.

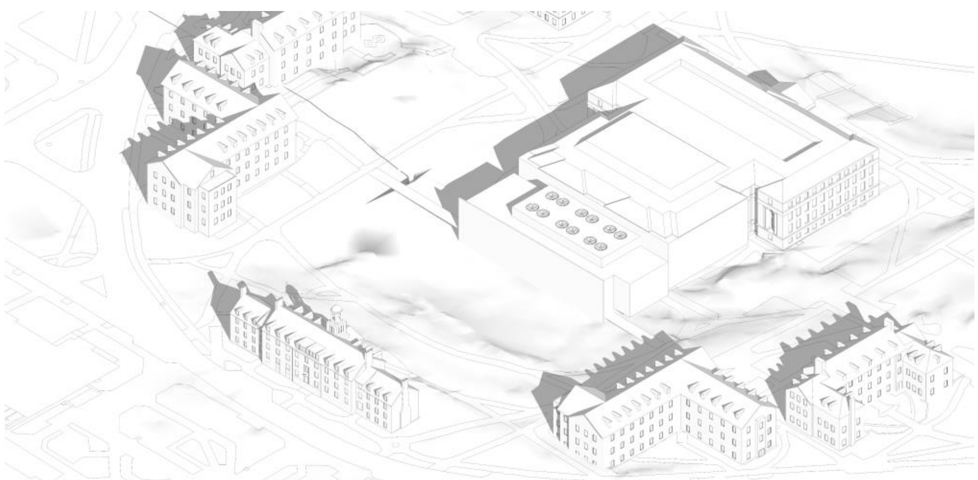

Figure 28- Graft (Source: Greg Goldstein)

Gateway was a study in which the structure did not engage McKeldin at all, instead forming a new edge to the West Mall on the North side relying on the existing edges of McKeldin and Anne Arundel to the East and West. The intent was to create a threshold to and from the Purple Line station creating a more private quad to the South. The northern elevation would engage the primary path running along the North of McKeldin Mall.

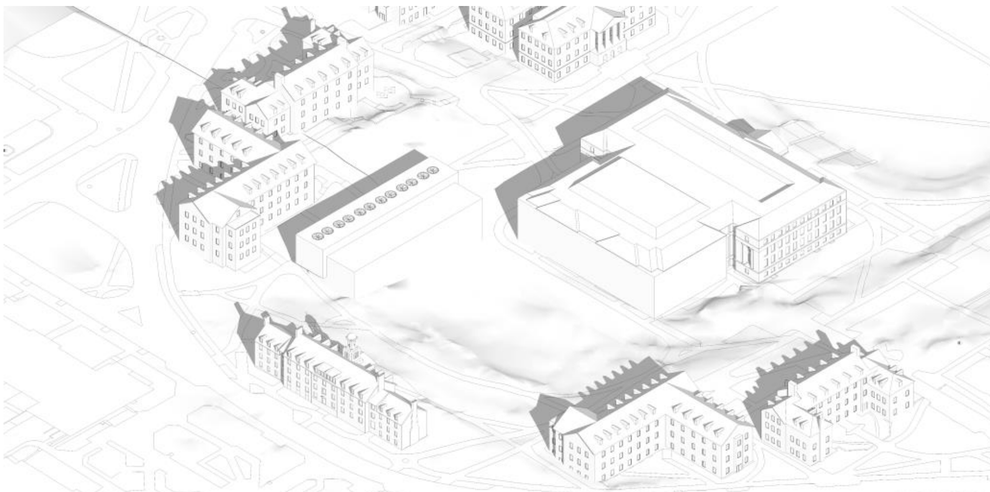

Figure 29- Gateway (Source: Greg Goldstein)

Energy Modeling

In order to determine which scheme would be developed, schemes were modeled and tested for solar heat gain coefficients in Autodesk Formit. It was the intent to compose the SCUB functions within based off of high or low passive heat gain in order to increase efficiency of heating and cooling systems. Areas with low solar heat gain coefficients would host programs such as studios and water chillers, while areas with high solar heat gain coefficients would host water heating program.

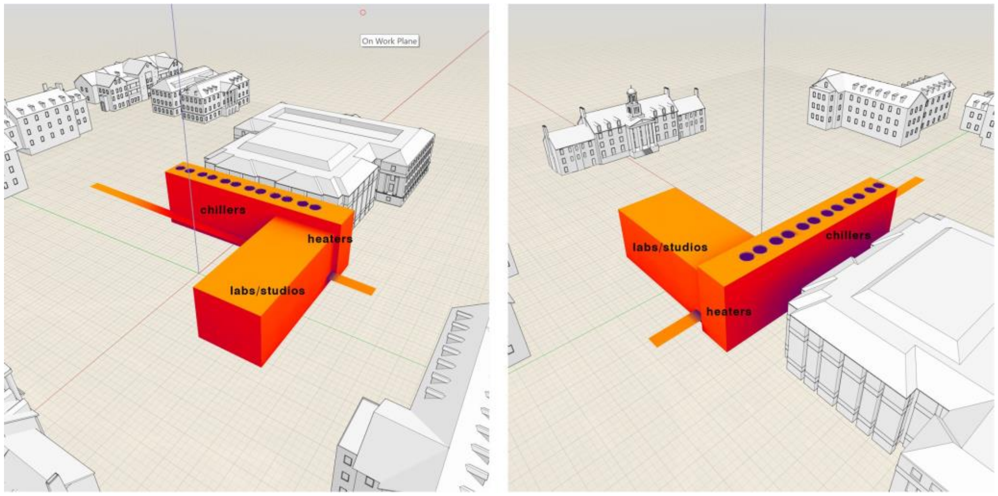

Figure 30- Head & Tail, Solar Heat Gain Coefficient (Source: Greg Goldstein)

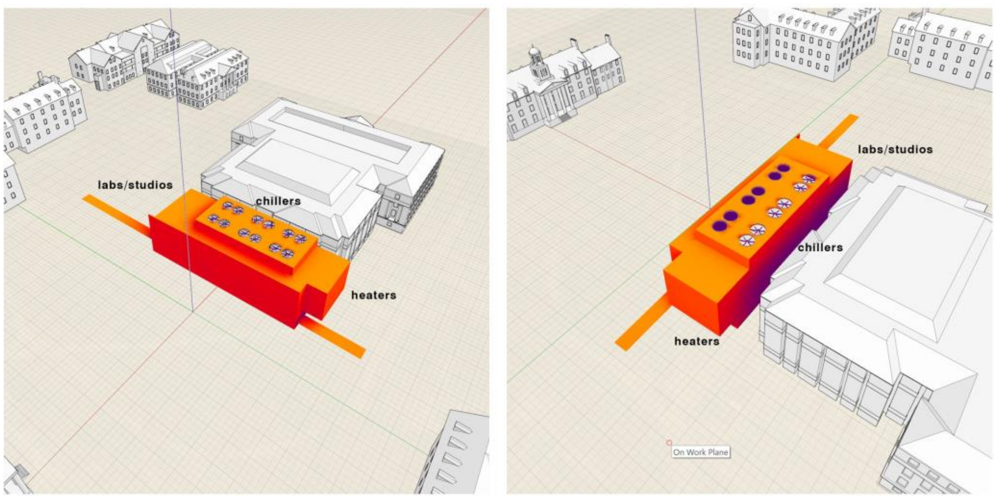

Figure 31- Graft, Solar Heat Gain Coefficient (Source: Greg Goldstein)

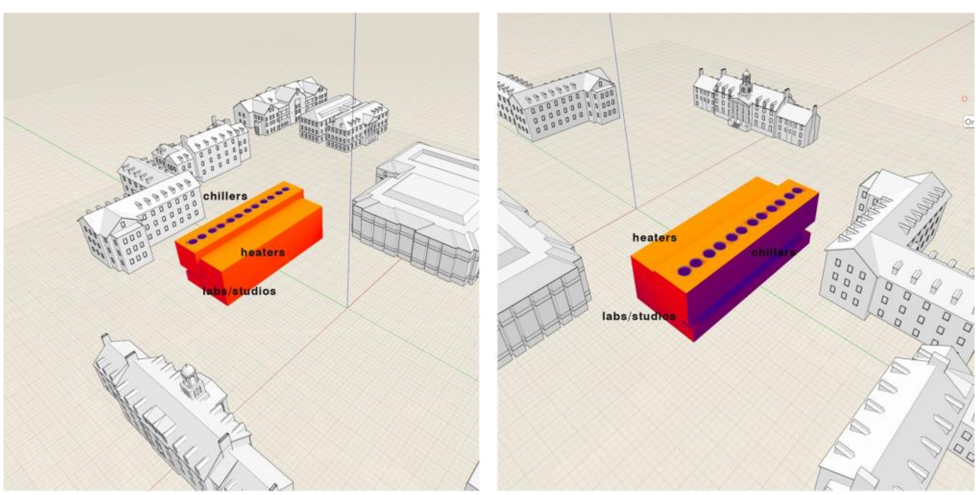

Figure 32- Gateway, Solar Heat Gain Coefficient (Source: Greg Goldstein)

Faces with low solar heat gain would be displayed as purple while faces with high solar heat gain would be displayed as orange. Taking into account both the variance of solar heat gain performance as well as the quality of urban design, **Graft** was ultimately chosen as the design scheme to expand upon. Not only did its proximity to the rear of McKeldin provide a zone of low heat gain in which studios and chiller systems could thrive, but its southern end provided an excellent location for heating program while not over-exposing space for educational program. While the Gateway scheme provided a larger zone with low heat gain, this would not only serve as a detriment in the winter for localized heating but provided a much larger zone to the south with a high solar heat gain coefficient. The Head and Tail scheme was least desirable in performance as it provided too much passive solar heat gain and nearly no zones of low solar heat gain.

Design Solution

The final design, a development of the graft scheme, would become a conduit for the flows of people, energy, and knowledge. On an urban scale, ramped public circulation routes were formed along the west elevation of MSID, between MSID and McKeldin, and a new East/West route was formed through the center, injecting itself into McKeldin Library. An expansion to Jimenez Hall and an additional proposed Residence Hall to the South of McKeldin reinforce quads to the North and South of the library, visually connected by the planting of new flowering trees. Mediating between old and new, an atrium was designed in the interstitial area between the library and MSID hosting the primary North-South circulation route. Stair towers and a celebratory stair within the atrium aim to tap into public circulation, providing the ability for students, faculty, and visitors to enter MSID or McKeldin at various points.

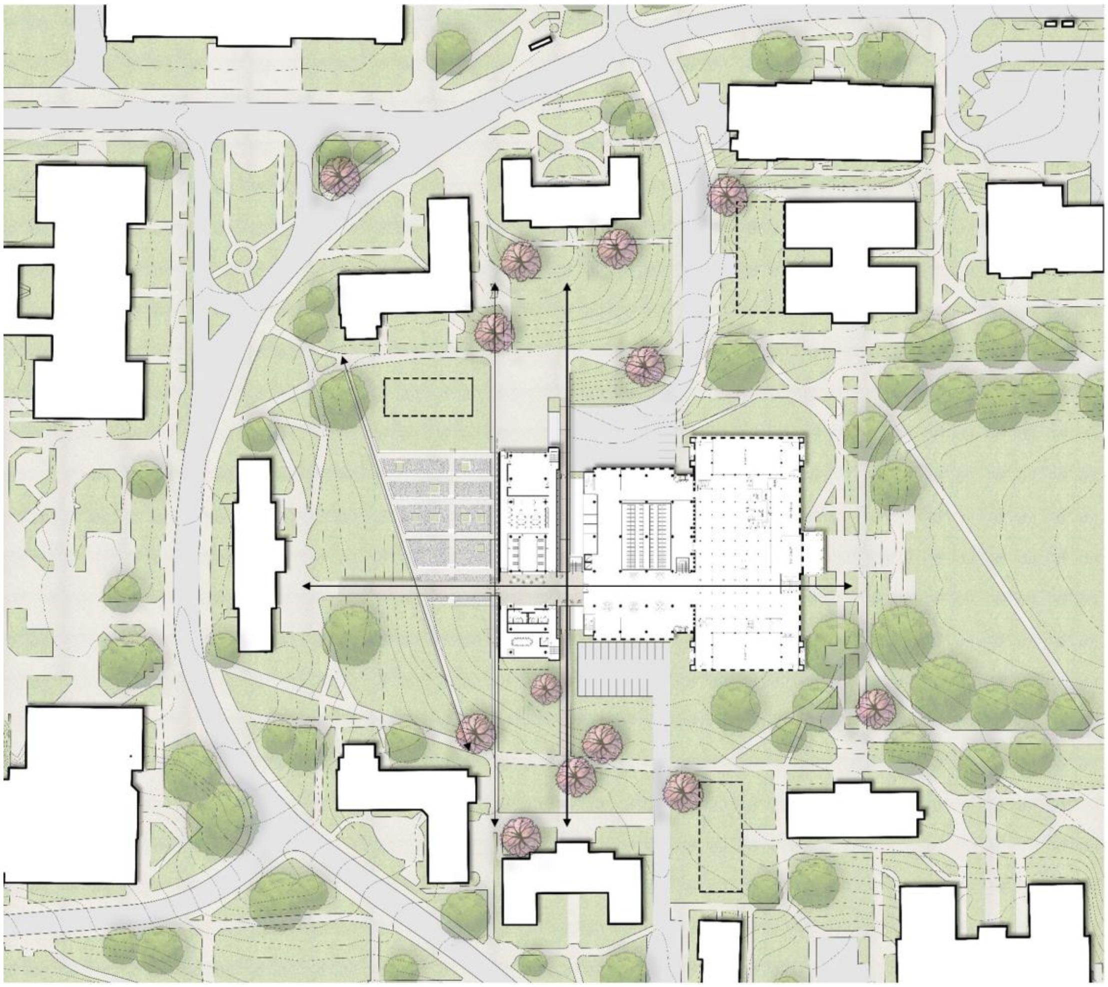

Figure 33-Site plan & circulation. (Source: Greg Goldstein)

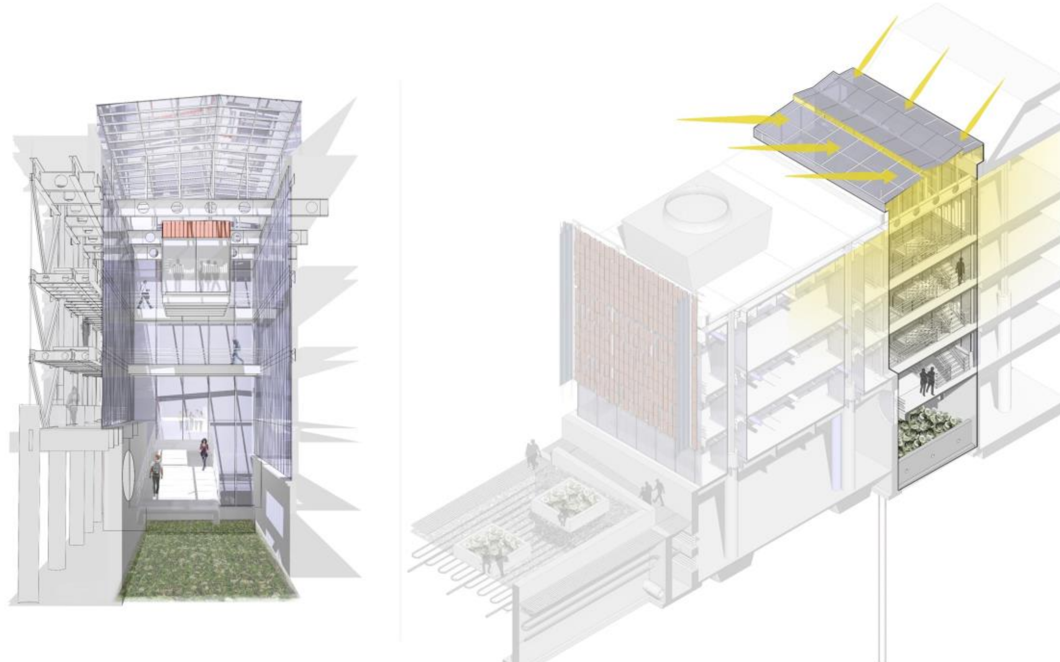

Figure 34- Atrium mediates between old and new. (Source: Greg Goldstein)

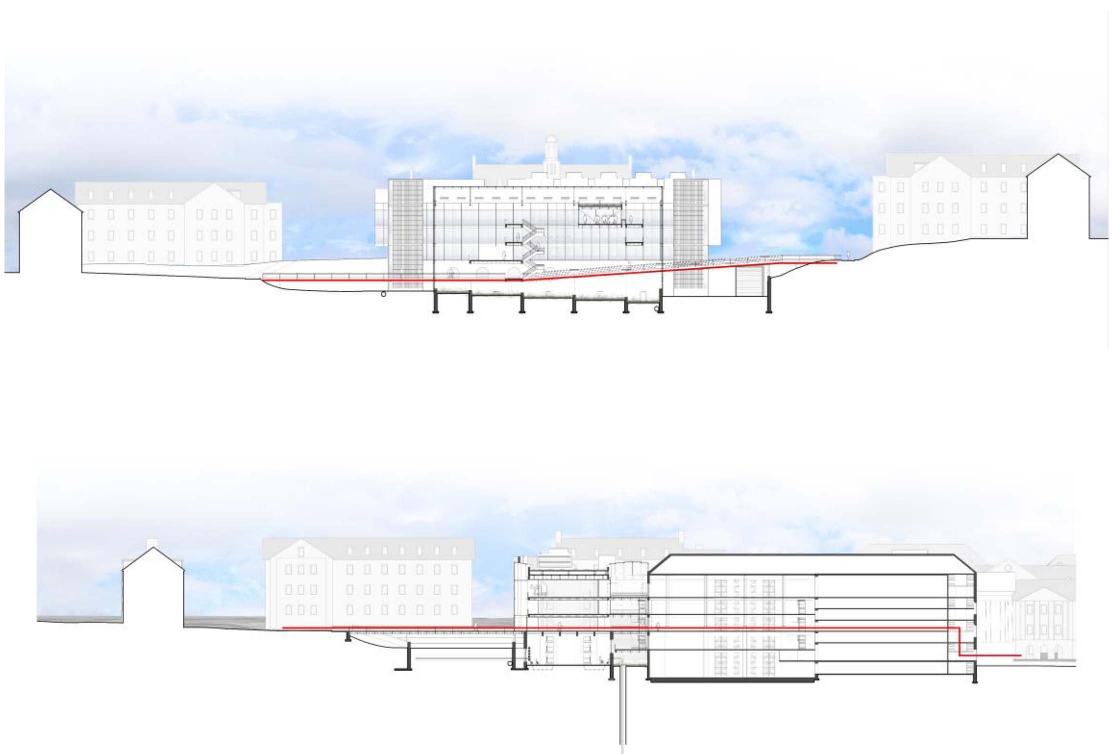

Figure 35- From top to bottom: circulation through atrium, circulation through library (Source: Greg Goldstein)

Aesthetically, it was important for MSID to respect the common architectural language of Colonial Revival while at once not appearing apologetic. McKeldin's East façade was diagramed to form the exterior proportions of MSID. A high rusticated podium was established followed by a broad center band with a visually lighter band meeting the sky. The North and South elevations of McKeldin's addition were re-skinned to aesthetically match the original library. On an urban scale, the goal was to unify new and old to create a more relatable entity. A bay still exists which visually separates both halves of the library, allowing slight changes in brick color/quality when re-skinning the addition.

Figure 36-diagramming proportions of McKeldin (Source: Greg Goldstein)

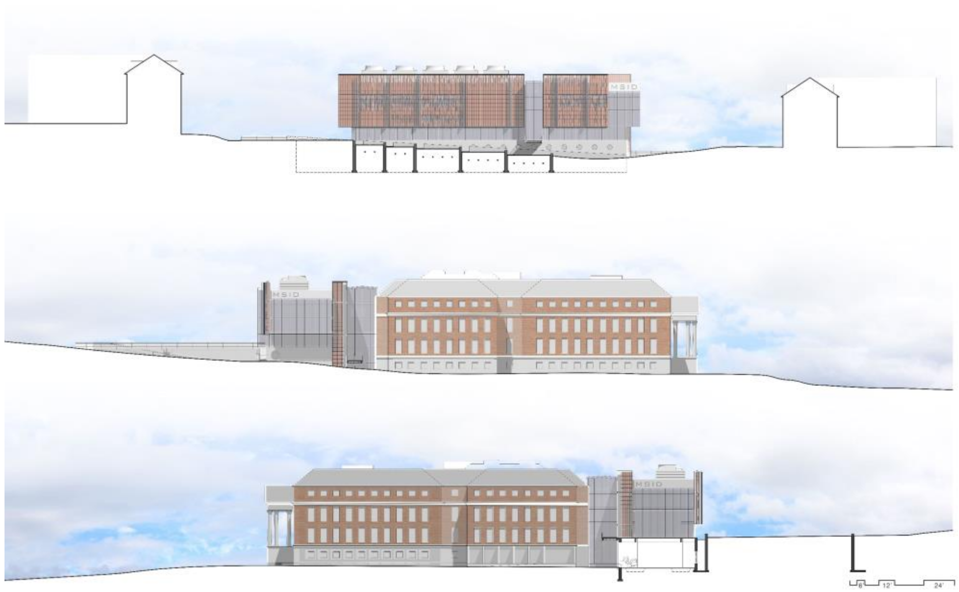

Figure 37- from top to bottom: W elevation, S elevation, N elevation (Source: Greg Goldstein)

The program of SCUB was dispersed vertically through the building to at once immerse occupants in technology while maximizing efficiency of passive solar gain. Much of the mechanical infrastructure required is housed in a spacious earth-bound podium, accessed on the North end by a new loading dock servicing both MSID and McKeldin. McKeldin's loading dock on the south end becomes handicap parking. Collaborative studio spaces and a workshop occupy the Northern end of MSID's bar building, the workshop opening up to a broad terrace above the podium, welcoming traffic to and from the purple line and channeling them around or through MSID. The South end of MSID hosts modular steam to water heat exchangers on the top floor to maximize solar heat gain coefficient, with a "plug and play" laboratory and automations control below. At the heart of MSID rests a vertical bank of modular water chiller units serviced by a large cable lift system, allowing forklifts access to both the bank, and the heat exchangers.

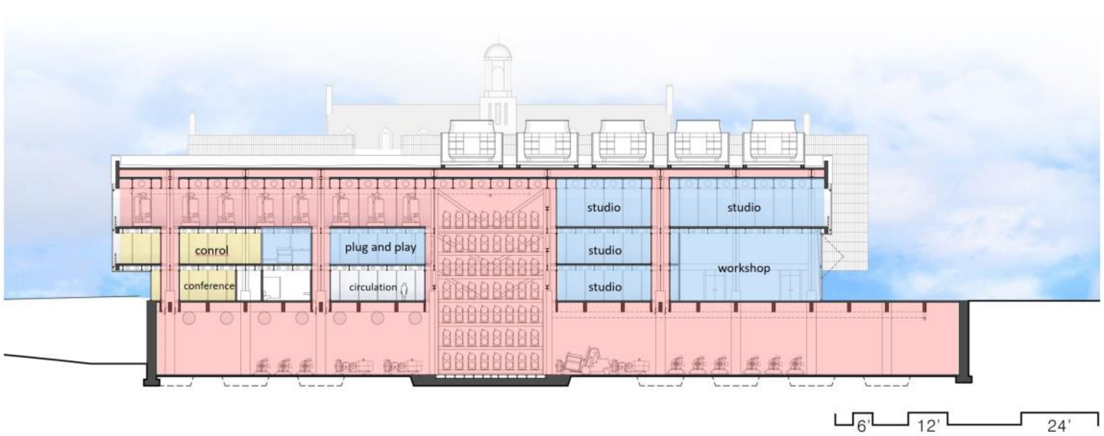

Figure 38- Programmatic Distribution. (Source: Greg Goldstein)

The chiller bank hosts modular two stage steam absorption chillers. Absorption chillers do not require electric motors, instead operating entirely on steam. Steam is routed from the South end through the podium where it is initially fed through heat exchangers. The steam then condenses and enters flash tanks where it returns to steam form in order to feed the absorption chillers. If the absorption chillers are supplied by unfired steam from a comb. turbine, the system has the capacity to reduce district water cooling costs by over 70%.[27] Supplemented by geothermal loops, cooling towers are located on the roof for ventilation and the potential for free cooling in colder months. Air handlers with added heat coils tap into campus water systems to heat and cool MSID when passive systems cannot.

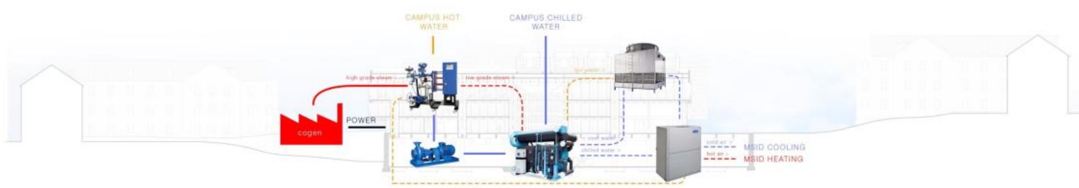

Figure 39- Flow Chart. (Source: Greg Goldstein)

MSID injects itself into McKeldin Library's addition. Beyond re-skinning its faces, several floors within are removed and space is made via the insertion of an automated book retrieval system. The design of McKeldin's addition is diagrammatically resolved to accommodate for this system, making room for new lecture halls, study carols, and central gathering spaces. The vertical storage banks in both MSID and McKeldin form a dialogue of mechanized efficiency on either side of

[27] RMF Engineering, CDM Smith Group. "UMCP Facilities Master Plan.". *University of Maryland, College Park,* (2012). Table 3-10.

the central atrium.

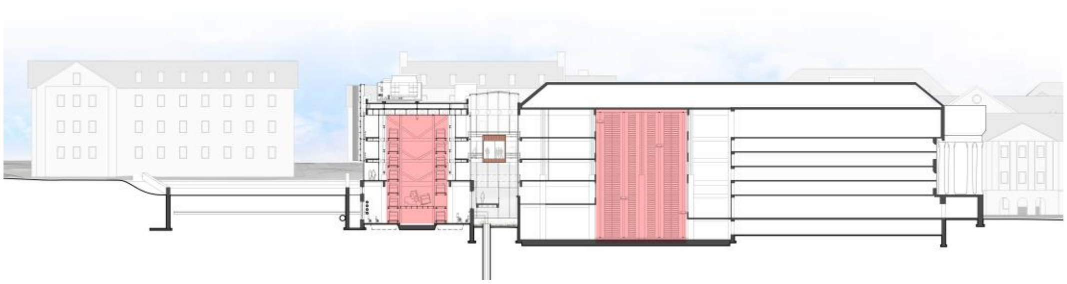

Figure 40- Transverse Section. Vertical bank dialogue. (Source: Greg Goldstein)

The Western façade of MSID is composed of photocatalytic ceramic tiles. These tiles, covering over 6000 sq ft, have the capacity to offset emissions from 55 cars.[28] Tiles are mounted on steel rods, able to pivot in order to provide views out and light in while blocking unwanted southern/western direct light. Cast with red pigment titanium dioxide, the tiles situate themselves within the context of UMD's brick campus in a respectful yet unique manner. Solar thermal water heaters may be clipped to the façade at intervals in order to supplement MSID's heating through radiant applications.

[28] Casalgrande Padana. "*Ceramics for Façade Applications." p. 15. Retrieved from* www.casalgrandepadana.com

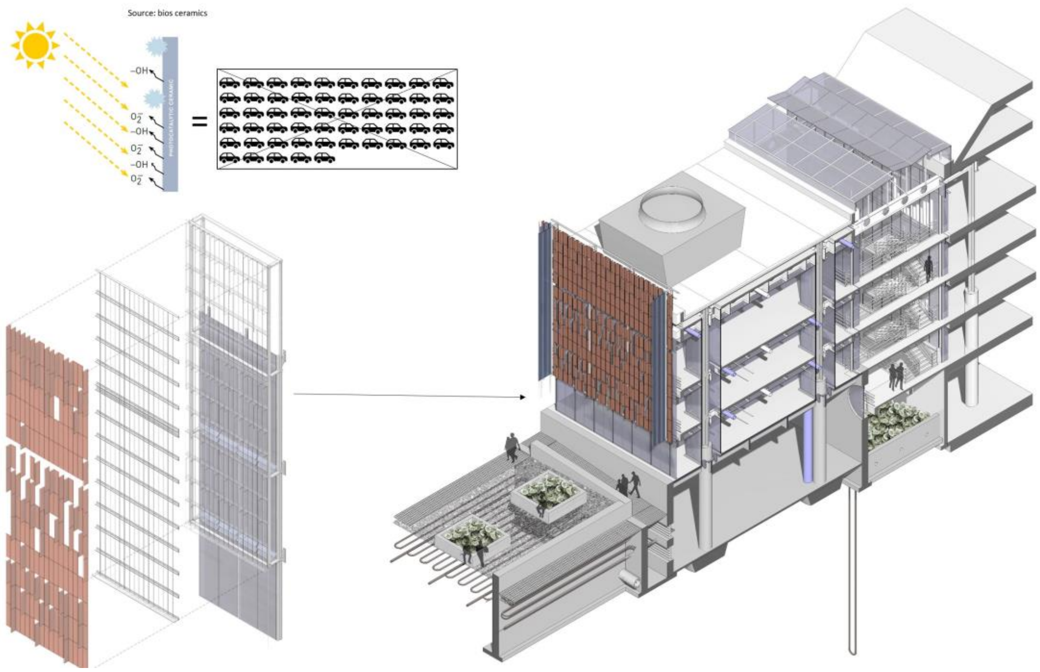

Figure 41 - Facade & Axonometric Section. (Source: Greg Goldstein)

The mechanical podium on which MSID sits is ventilated through a grated ramp along its west end. Thermal Chimneys protrude from the podium through the occupied structure at regular intervals, exhausting waste heat into a roof plenum. The plenum hosts fan units to propel air out of its west end, allowing exhaust air to be filtered by photocatalytic applications. At the same time, the roof plenum has the ability to skim the hottest of the air from the central atrium during the summer, ejecting it once again out of its west face. Thermal chimneys are lined with PCM glass – a phase change material with the capacity to absorb heat in the winter while rejecting heat in the summer.[29] These chimneys have the capacity to absorb heat from mechanical systems in the winter, slowly releasing heat in the form of radiation to

[29] Manz, H, P.W Egolf, P Suter, and A Goetzberger. 1997. "Tim-Pcm External Wall System for Solar Space Heating and Daylighting." *Solar Energy* 61 (6): 369–79. doi:10.1016/S0038-092X(97)00086-8.

provide passive heating in the winter. Hot air may be rejected with a baffle system at the base of the chimneys to cater to warmer months when the building has less use.

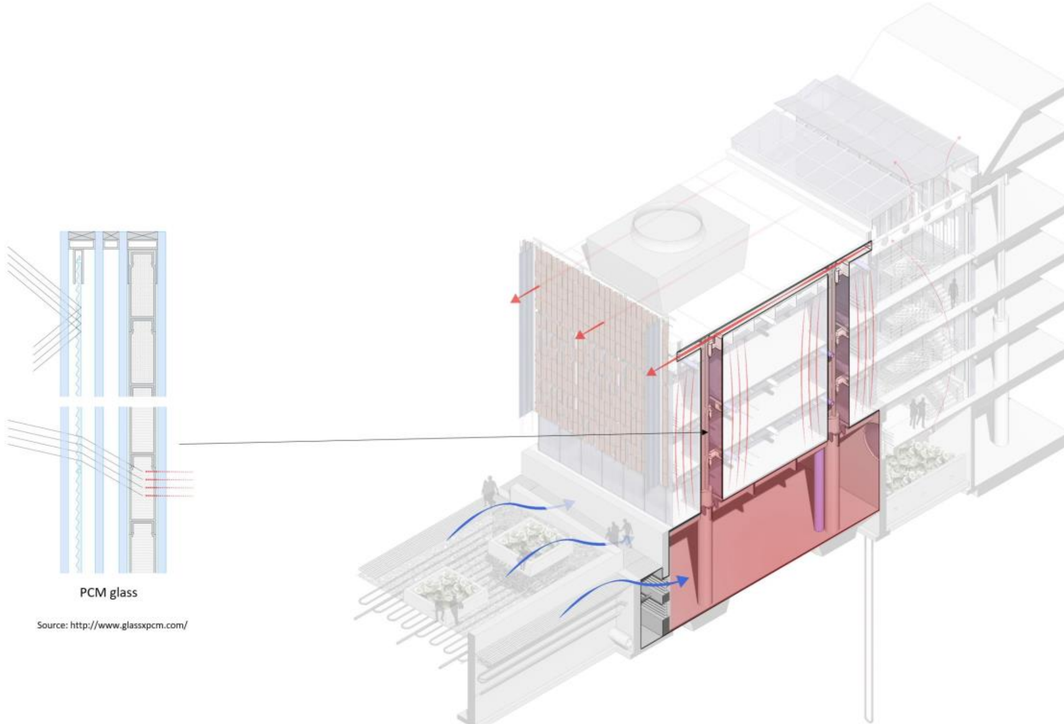

Figure 42- Mechanical podium and thermal chimneys (source: Greg Goldstein)

On the West side of MSID, landscape slowly descends along the mechanical podium in the form of terraced rock gardens. Below the rock gardens, campus hot water pipes slowly release heat to be recaptured in surface geothermal loops, heating the rocks. This forms yet another tactile connection between visitors/occupants and the systems within MSID. Planter boxes are placed periodically throughout the rock gardens. Grated paths and low terraces allow visitors and occupants to traverse the landscape, sunbathe, or sit and chat.

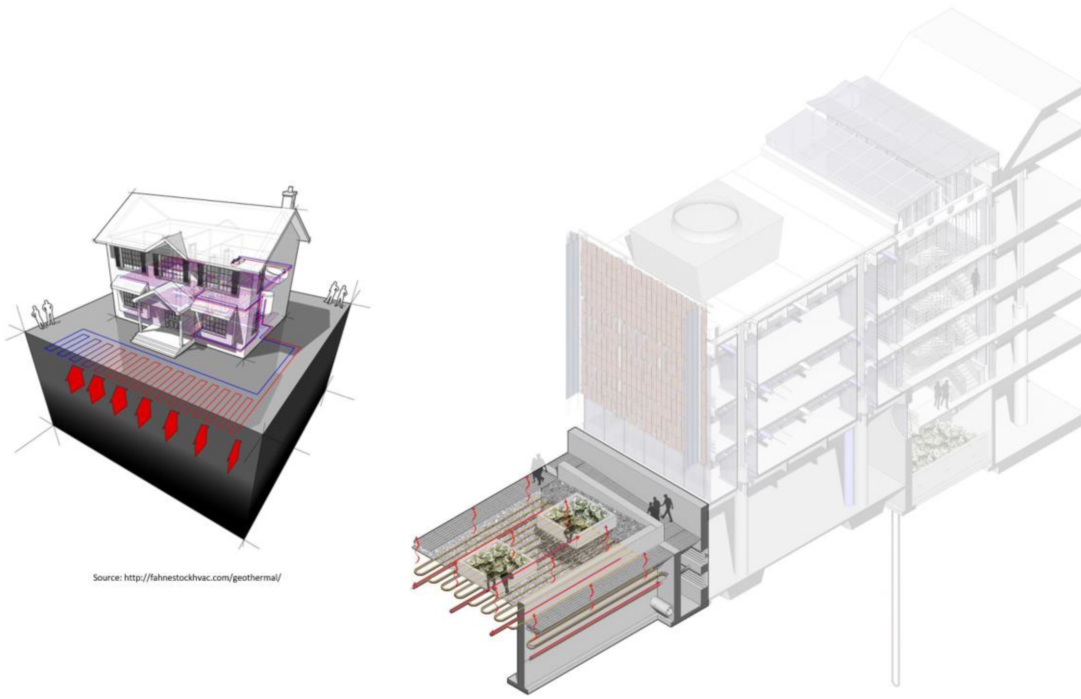

Figure 43- Landscape heating & features. (Source: Greg Goldstein)

In order to accommodate for the routing of ducts and pipes, a two-way crenellated beam system is applied. Larger trunk lines may be routed through thermal chimneys, where they are then distributed in smaller branches through floor/ceiling planes. The beam system is exposed through the use of transparent flame retardant polycarbonate sheets sealed with a flame retardant gasket. Splice connections are applied between the beam system and composite steel angle columns to allow for assembly of floor planes on the mechanical podium where they may be lifted and bolted into place upon completion. Curtain walls may then be clipped onto the sides of the construction assembly. This method requires less use of cranes and elevated work stations, saving both money and time in the construction process.

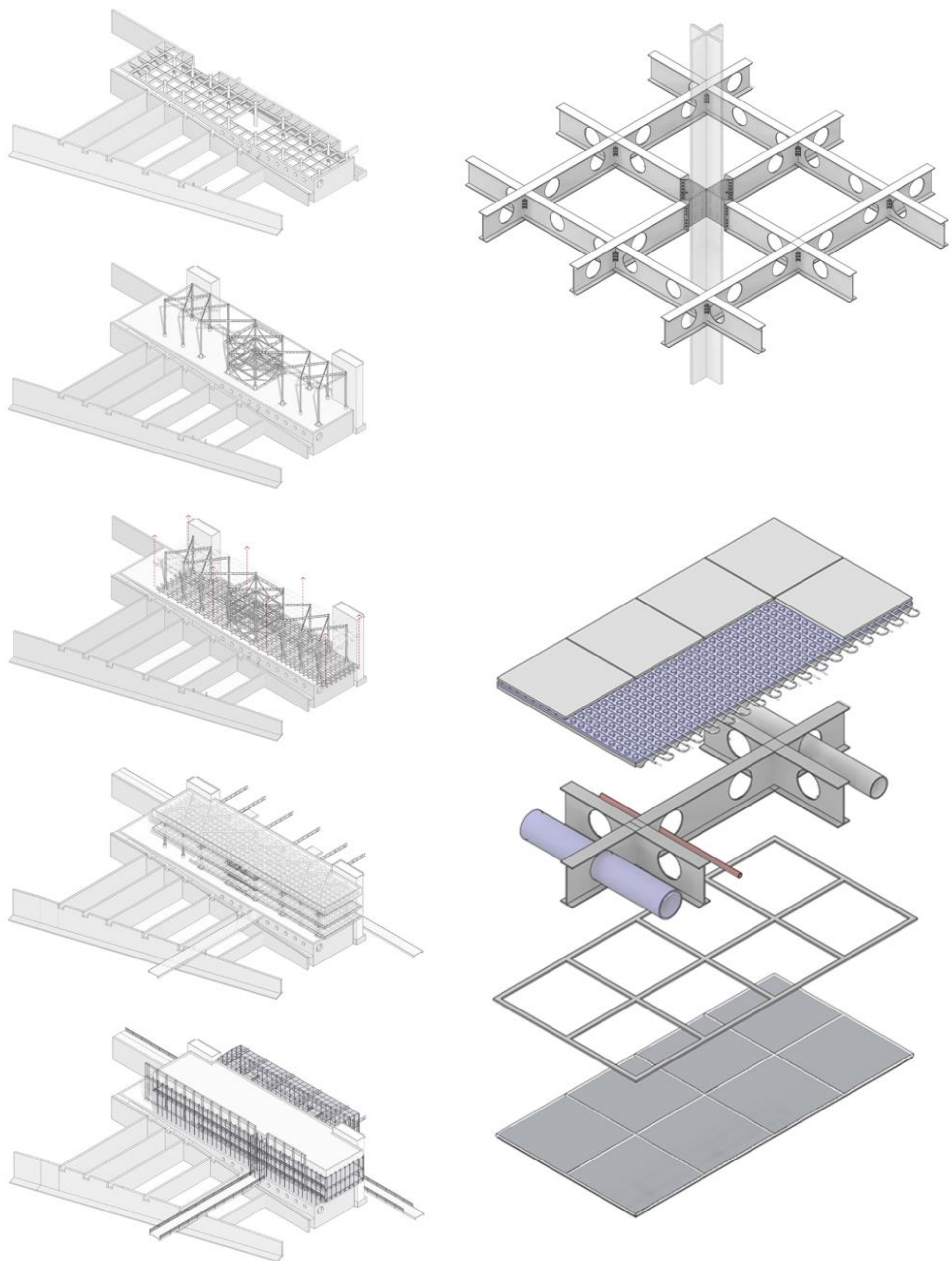

Figure 44- construction methodology. (Source: Greg Goldstein)

Chapter 5: Conclusion

Overview

This thesis explored the impact an architectural infrastructure might have on education and awareness in the fields of energy efficiency, sustainability, and integrated design. Points of focus were performance, maintenance, accessibility, and public engagement. University of Maryland's SCUB concept was researched and applied as a point of departure, serving as the basis for a new school of integrated design that could harness SCUB program for both education and architectural performance.

Reflections

A primary intent of this thesis' marriage between architecture and mechanical infrastructure was to improve performance of each, respectively. While the design solution was able to harvest benefits from mechanical infrastructure to improve architectural performance, it failed to prove that mechanical infrastructure's *performance* could be improved through architectural design/form. However, solutions were investigated that could improve aspects of mechanical operations related to maintenance and public engagement.

A possible design study as an alternative to the proposed solution would instead be an investigation of an architectural intervention on multiple scales. While this design solution examined mechanical infrastructure on a campus level, the city or state scale could be imagined – conversely, architectural/mechanical integration could be examined on a much smaller scale such as that of a small neighborhood or even a single home.

While “light” forms of energy modeling were conducted as part of the conceptual design process, further energy modeling related to the design solution would be welcomed. A life cycle and cost analysis of MSID studying aspects such as embodied energy and projected energy usage intensity would help determine viability.

Ultimately, this architectural investigation bridged into various disciplines. While University of Maryland Facilities Management proved an extremely useful resource, further collaboration between the architectural and engineering departments in the future could produce interesting results. As a field relying heavily on collaboration, architectural education should further reflect realities of the field to both prepare students, and further the intellectual discussion of how the built environment can not only accommodate technology but harmonize with it. In his ten books of architecture, Vitruvius provides an allegory of the first fire. Before man could utter a word, they gathered about the flames and began to communicate – through this, the social practice of architecture was born.[30] I challenge all disciplines enmeshed in the art of building to question how we can reignite this flame in a new paradigm of integrated design.

[30] Pollio, Vitruvius, M.H. Morgan, Herbert Langford Warren. *The Ten Books on Architecture.* Columbia, SC: Harvard University Press, 1914.

Bibliography

1) *Energy Efficiency Trends in Residential and Commercial Buildings*(Rep.). (n.d.). US Department of Energy. Retrieved November 27, 2017, from https://www1.eere.energy.gov/buildings/publications/pdfs/corporate/bt_stateindustry.pdf
2) *A Common Definition for Net Zero Energy Buildings.* US Department of Energy, the National Institute for Building Sciences. September, 2015.
3) KM Fowler, "Federal New Buildings Handbook for Net Zero Energy, Water, and Waste." *US Department of Energy, Pacific Northwest National Laboratory*. Retrieved November 29, 2017 from
4) "Zero Net Carbon (ZNC): A Definition." (n.d.). *Architecture 2030*. Retrieved November 27, 2017, from http://architecture2030.org/zero-net-carbon-a-new-definition/
5) Cara Carmichael, Katrina Managan. "Reinventing Existing Buildings: Eight Steps to Net Zero Energy." *Institute for Building Efficiency, Johnson Controls*. May, 2013.
6) KM Fowler. "Federal New Buildings Handbook for Net Zero Energy, Water, and Waste." *US Department of Energy, Pacific Northwest National Laboratory*. Retrieved November 29, 2017 from https://energy.gov/sites/prod/files/2017/08/f35/net_zero_new_buildings.pdf
7) Carlo Colella. "University of Maryland Climate Action Plan 2.0." Carlo Colella, *University Senate.* Retrieved November 28, 2017 from https://www.senate.umd.edu/sites/default/files/resources/MeetingMaterials/04062017/Climate_Action_Plan_2.0_16-17-30.pdf
8) "University of Maryland Utility Dashboard." *UMD Facilities Management*. Retrieved November 30, 2017 from http://terpfootprints.umd.edu/
9) "US Energy Use by Property Type". Energy Star. March, 2016.
10) RMF Engineering, CDM Smith Group. "UMCP Facilities Master Plan.". *University of Maryland, College Park*, (2012).
11) David D Cosner Sr. "Failing Infrastructure Creates Invisible Crisis at University of Maryland." *University of Maryland, College Park*, (2012).
12) Aldo, Rossi. "The Architecture of the City, trans. Diane Ghirardo and Joan Ockman" *Cambridge, MA: MIT Press*, (1982), 29.
13) James Corner. "Terra Fluxus." *Terra Fluxus. Lotus International*. 2012.
14) James Corner. "Urban Metabolism, Rotterdam." *Rotterdam, Netherlands. Mediacenter Rotterdam.* 2014.
15) Gilles Delalex. "Go With the Flow: Architecture, Infrastructure and the Everyday Experience of Mobility." *Gummerus Printing, Vaajakoski, Finland.* 2006.
16) Koolhas, Rem. "The NS Interview: Rem Koolhaas, Architect." Interview by Samira Shackle. *New Statesman* May 2012. Retreived 12/7/17 from https://www.newstatesman.com/culture/art-and-design/2012/05/ns-interview-rem-koolhaas-architect
17) Stan Allen. "Points and Lines." *Princeton, NJ. Princeton University Press*. 1999.

18) Stan Allen. "Infrastructural Monument." *Cambridge, MA. Princeton Architectural Press*. 2016. P 56
19) "OSU South Campus Chiller Plant." 2013. Ross Barney Architects. Retrieved 12/10/2017 from http://www.r-barc.com/wp-content/uploads/2013/01/OhioStateUniversitySouthChiller.pdf
20) Ascher, K., & Marech, W. "The works: Anatomy of a city." *New York: Penguin Press*. 2005.
21) University of Maryland Facility Management. "Utility Assessment." *College Park, MD. RMF Engineering.* 2012.
22) University of Maryland Facility Management. "UMCP Utilities Masterplan." *College Park, MD. RMF Engineering.* 2012.
23) University of Maryland Facility Management. "Utility Assessment." *College Park, MD. RMF Engineering.* 2012.
24) University of Maryland Facility Management. "UMCP Utilities Masterplan." *College Park, MD. RMF Engineering.* 2012.
25) University of Maryland Facilities Master Plan 2011-2030. Retrieved 5/17/2018 from https://www.facilities.umd.edu/documents/fmp/2011-2030%20facilities%20Master%20Plan.pdf
26) MAC to Millenium. Retrieved from http://www.lib.umd.edu/ARCV/macmil/index.html 5/18/2018.
27) RMF Engineering, CDM Smith Group. "UMCP Facilities Master Plan.". *University of Maryland, College Park,* (2012). Table 3-10.
28) Casalgrande Padana. "*Ceramics for Façade Applications." p. 15. Retrieved from* www.casalgrandepadana.com
29) Manz, H, P.W Egolf, P Suter, and A Goetzberger. 1997. "Tim-Pcm External Wall System for Solar Space Heating and Daylighting." *Solar Energy* 61 (6): 369–79. doi:10.1016/S0038-092X(97)00086-8.
30) Pollio, Vitruvius, M.H. Morgan, Herbert Langford Warren. *The Ten Books on Architecture.* Columbia, SC: Harvard University Press, 1914.